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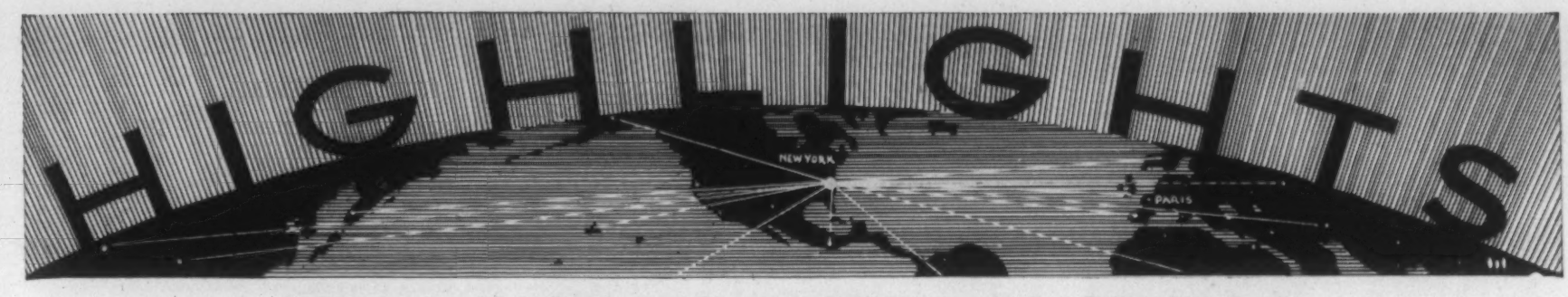

Written by the Abstract Section Editors and the Editorial Staff

DO YOU want to know what metallurgical engineers are saying, the world over? Look in the Current Metallurgical Abstracts. Here are some of the points covered by authors whose articles are abstracted in this issue.

A Criterion of Quality of Cast Iron

According to Challonsonnet (page MA 114 R 2) the modulus of elasticity is the best criterion of the quality of cast iron for engineering use.—H.W.G.

"Churning" of Cast Iron

Lunt (page MA 114 R 3) and Girardet (page MA 115 L 1) both argue for the agitation or "churning" of cast iron in order to produce the desired nodular, finely distributed graphite. —H.W.G.

Heat Treaters Do the Impossible

According to Sefing and Trigger (page MA 119 L 2) "coarse grain steels always crack in light and medium sections," but heat treaters have been successfully hardening such steels. One suspects that the experimental conditions were out of line with good practice.—O.E.H.

Deformation and Quenching of Steels

Ameen has studied the deformation of tool steels during hardening and annealing (page MA 119 L 5) and Honda has more to say about the mechanism of quenching steels (page MA 121 L 1). —O.E.H.

Steels Prefer Fresh Fish Oil for Bath

Hara (page MA 119 L 8) has studied efficiencies of several quenching oils and proposed equations for the relations of viscosity and temperature and of mean cooling velocity and the coefficient of viscosity. Old fish oil was low in cooling velocity.—O.E.H.

A New Field in Heating

For low temperature industrial heating the development of convection heating furnaces is a recent and important step in the line of progress. An article reviewing developments in this equipment is abstracted in this issue (page MA 122 L 1). Darrah also describes applications in "Metal Progress" for Nov. 1935.—M.H.M.

Less Expansion of Rails Welded End-to-End

Rietsch and Croskell (page MA 127 L 2) point out that rails welded end-to-end into long lengths actually expand with increase in temperature only about half what they would be expected to on the basis of tests on small specimens. —H.W.G.

Oxide Films on Steel

An oxide film on a steel surface, though invisible to the eye, may have an effect in various ways, particularly in plating work, far greater than one might suppose. A method for detecting and studying such invisible films has been described which is essentially a modified Preece test—a copper nitrate solution being applied as a drop on the surface (page MA 132 L 9).—H.S.R.

Magnetic Testing

The Research Department, Woolwich, (page MA 138 L 3) has gone into the field of non-destructive testing by magnetic powders. They describe their test for cracks in a steel cylinder (the flux goes 'round and 'round).—C.S.B.

Certain Alloys That Are Not "Steel"

According to Norbury (page MA 141 L 4) the term "steel" should be reserved for material without carbide eutectic or graphite eutectic in the cast structure, so that the crankshaft and piston alloys that are cast white are not properly called steel.—H.W.G.

More About Grain Refinement

Tammann and Boehme (page MA 141 L 2) make some interesting deductions as to grain size resulting from cooling through the inversion ranges of the gamma loop. If the concentration of the loop-forming element is less than 4/10 of the possible concentration, the delta-gamma change gives grain refinement. When it is up to 8/10 there is no grain refinement. This reminds one of Tammann's old "rule of eighths" in regard to alloying and corrosion, a mathematical conception none too well borne out by facts. Generalizations help the memory, but it's unsafe to trust them implicitly without a lot of proof. —H.W.G.

The "Disorder Constant" or Constant Disorder

Oelander discusses the "disorder constant," whatever that means (page MA 141 L 6). We would have no difficulty in getting the idea of constant disorder, for we've had it since the new deal started.—H.W.G.

Uranium Steel

The last few years have shown considerable interest in the possibilities of use of the lesser known elements as alloying additions to steel (page MA 146 R 2). Generally the development of particular properties imparted to steel by such additions has more than justified the necessary time and expense. At present it remains for the future to disclose what use we can make of uranium.—V.V.K.

Films vs. Wear

The importance of films on metals as an aid to corrosion resistance has long been recognized. The presence of oxide films is now suggested to be responsible for the extraordinary behavior of a German rail steel which, while possessing only half the breaking strength of an American rail steel, showed only 70-80 per cent of its wear (page MA 150 L 3).—V.V.K.

Scaling of Steels

A comprehensive investigation of the effect of alloying additions on the scaling of steel that is well worth careful study is that reported by Kiwit (page MA 150 L 5).—V.V.K.

Metals and Rocket Propulsion

"Aircraft Engineering" publishes a discussion by Ley (page MA 153 L 2) of high temperature properties of metals in respect to rocket propulsion. This sounds rather like "Popular Mechanics" metallurgy and engineering. Still, cast iron crankshafts, a hood full of die castings, insulation firebrick, controlled furnace atmospheres, air conditioning and so on all sounded odd at one time. Surface hardening by heating and quenching in the twinkling of an eye and pre-fabricated metal houses still sound a little odd to most of us, but the former at least, seems to be on its way. —H.W.G.

Protective Coatings on Metals

Another thing we'd like to see more signs of interest in is the problem of fitting a metal to take and hold paint or other protective coatings, so the abstract from "Sheet Metal Worker" on a metal clad insulated model home in which sheets specially prepared for painting are mentioned, pleases us (page MA 153 L 2).—H.W.G.

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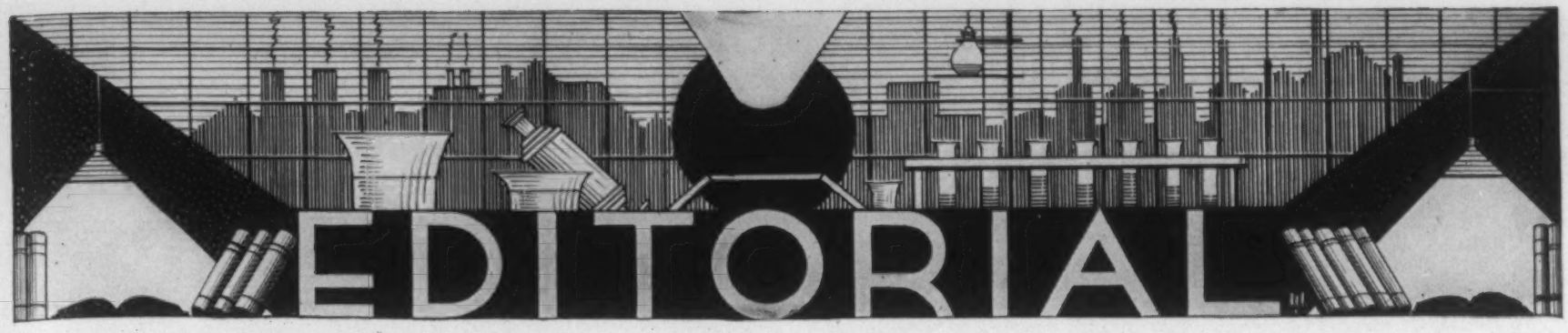


Precision—Reproducibility—Accuracy

A RECENT pungent editorial in METALS & ALLOYS expresses pity for the poor analyst called upon to make routine analyses of so many elements in the alloys of today and the future. Well may such pity be expressed. The poor analyst, who sometimes commiserates with himself, is thankful for that measure of understanding. That, however, is insufficient. There must be a greater mutual understanding between the metallurgist and the chemist as to what the former wants and needs ("want" and "need" are not necessarily synonymous) and what the latter is prepared to supply. More people must be cognizant of this and related points.

Familiarity breeds contempt, or at least lack of appreciation at times, and many metallurgists use the terms "chemist" and "analyst" interchangeably. Perhaps, if the long needed distinction were set up, progress for all concerned might be greater, for an analyst, highly skilled as he may be on repetitive work and laboratory technique, is not necessarily one who has the outlook of the analytical chemist. The one is fundamentally a product of vocational training, the other of professional education. Sometimes, the products are combined in one man or the two types are co-ordinated in one organization or laboratory.

When that desirable result is coupled with an understanding metallurgical, or perhaps engineering group, then the distinction between reproducibility, precision and accuracy in analysis is recognized or at least on the way to being so. How often, though is that the case? Consider the generally loose way in which the term "complete analyses" is employed; or the words "accurate" or "correct," or "trace." What do they mean? Like St. Paul, they may be all things to all men. Careful, conscientious repetitive work by the chemist-analyst should result, it is true, in reproducible results of known, often sufficient, or even an unnecessarily high degree of precision. Accuracy, which is less often required and certainly still less often attained, is even more dependent than precision upon the representative character and condition of sample, time, speed, reagents, equipment, and last but by no means least, personnel.

Requests to the chemist-analyst for a "complete analysis" obviously, at times, refer to the "formula." "Composition," in the true meaning of the term, might mean a "complete" breakdown of the alloy not only as elements but as combined. Easier to request than accomplish. Practically a "complete" is an ideal more often than an actuality.

As for the various possible interpretations of the word "trace," words fail. Patience also, at times.

Why do not more metallurgists realize these points when requiring or utilizing such data? In fact, why do not more laboratory heads or fellow chemists?

If then the one requiring an analysis does not know that precision is a matter of degree, while accuracy is not; if he does not know the degree which he requires; if he does not know the degree which is attainable under a particular set of conditions; then the proper function of the chemical laboratory is not appreciated and weighty but erroneous conclusions in whole or in part may be drawn on faulty, erroneous or incomplete data.

Obviously then, there must be a greater co-ordination of the metallurgist and the chemical laboratory. There are signs that force of circumstances is bringing this about. Not the least of these are the growing appreciation of the influence of minutiae and of elements and compounds, not heretofore determinable or even, at times, recognized as being present or absent in metals and alloys. Witness the growing comprehension that a refined metal is often only pure in degree and that some so-called "pure" or refined metals are for some purposes alloys in fact as well as in theory.

Emphasis on price and speed, while important factors that justify consideration, should not so often be the governing ones when analytical data is needed.

Metallurgists, as well as chemists, will do well to consider the sometimes revolutionary effects on the mental attitude and approach to a problem induced by a comprehension of the importance of the more unusual or newer methods of analysis such as are offered by fluorescence, spectrography, polarized light, the petrographic microscope, chemical microscopy, microanalysis, or X-ray diffraction. Any one or more of these might be needed to supplement or complement that which we usually think of as chemical analysis and be as important in their way as the indispensable metallographic microscope.—T. A. Wright.

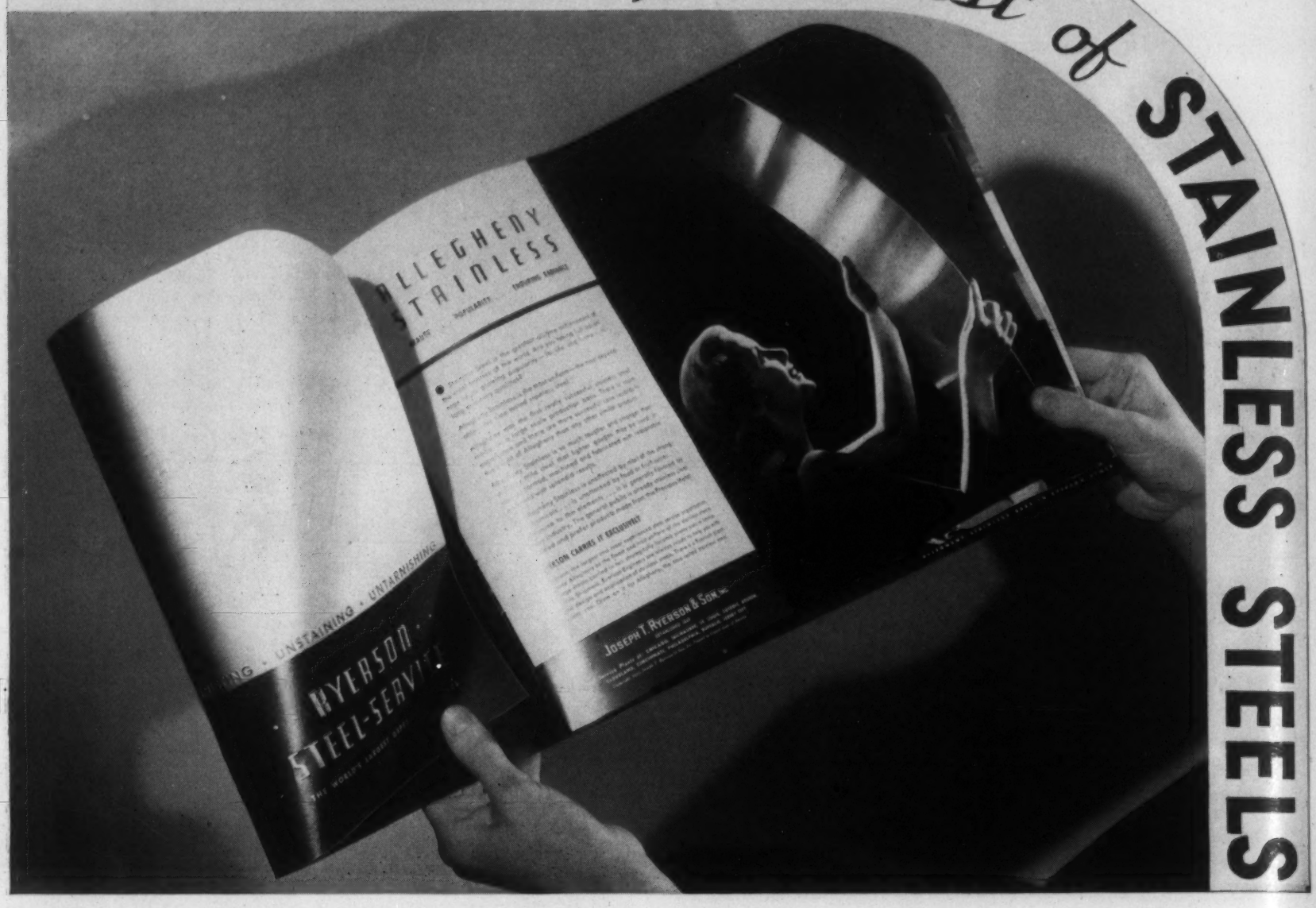
Committees

IN THE report of a committee of The Electro-Chemical Society, appearing in vol. 67, there is a section on "corrosion work in Europe, Africa and Australia," written by U. R. Evans. In the course of this report he comments as follows:

> Perhaps the most noteworthy tendency of corrosion research in Europe during recent years is the spread of the Committee System. For organizing ambitious series of exposure tests of a semi-empirical character, this has much to commend it. It would be almost impossible for a private investigator today to accumulate the necessary amount of material, prepared under carefully defined conditions. At the same time, it must never be forgotten that the committee system makes a very serious claim on the time and thinking power of those who otherwise would be starting really original work on new lines. There is little doubt that, throughout the world, the more fundamental side of

(*Continued on page 63*)

ALLEGHENY - *The Finest of* STAINLESS STEELS



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The Role of Copper in Wrought Steel

By CLYDE E. WILLIAMS and CLARENCE H. LORIG

Director and Metallurgist, Respectively, Battelle Memorial Institute, Columbus, Ohio.

COPPER HAS LONG BEEN used in small amounts to confer weather-resistance upon steel. In these amounts its effects upon mechanical properties are negligible. Nevertheless, in larger amounts, it becomes a true alloying, strengthening, element. It is a very cheap one.

These facts have led to the very recent commercial introduction of several low-carbon, high-yield-strength structural steel in which copper is one of the major alloying elements. It will doubtless also appear more and more prominently in other types of steel, in company with the other members of the family of alloying elements, as time goes on.

The base-lines which the metallurgist must start from in building a "tailor-made" alloy steel, in which specific properties are wanted, within a given range of cost, are the properties that each of the elements under consideration confer upon carbon steel.

Some of this fundamental information on copper steel, based on information from the literature, and on work at Batelle Memorial Institute, was published by Gregg and Daniloff[1] in 1934. Since then additional work at Batelle has brought out further facts and enables the presentation of a somewhat more definite summary of the alloying role of copper.

Effect of Copper on Mechanical Properties of Steel

In amounts above 0.5 per cent, copper increases the strength and hardness of steel, but reduces the ductility. These effects on strength and hardness increase with copper, but the rate of increase falls off beyond 2 per cent. As the strength of steel is increased by copper, the ductility decreases, just as is the case when carbon is employed in straight carbon steel. However, the loss in ductility for a given increase in strength is less with copper steels than with plain carbon steels.

The effect of copper on properties of steels varies with heat treatment; yet there are certain influences of copper which remain unchanged irrespective of the treatment given the steels. The marked increase in yield strength with copper and the relatively mild loss in toughness which accompanies the increase in yield strength are examples of these influences.

In Fig. 1 the properties of normalized copper-bearing steels are plotted with reference to carbon content. Here the tensile strength, the yield and the Brinell hardness rise with carbon content, and the reduction of area and the elongation diminish with carbon content. Each 1 per cent copper added to the normalized steel increased the tensile strength about 20,000 lbs. per sq. in., the yield strength from 15,000 to 20,000 lbs. per sq. in. and the Brinell hardness by 35 points, while it decreased the reduction of area and the elongation about 3 per cent. Over the range of carbon content employed in these tests, the effects of copper did not diminish.

These trends in properties indicate that the actions of copper and of carbon in steel are somewhat alike. There are these differences, however. The effect of copper on yield strength increase is greater than that

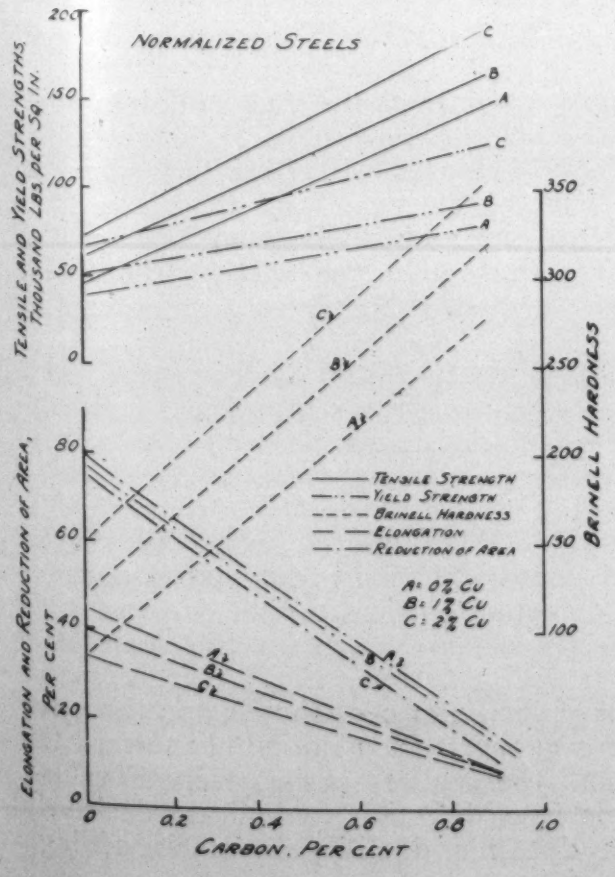


Fig. 1.—Properties of Normalized Steels Containing 0, 1, and 2 Per Cent Copper with Reference to Carbon Content.

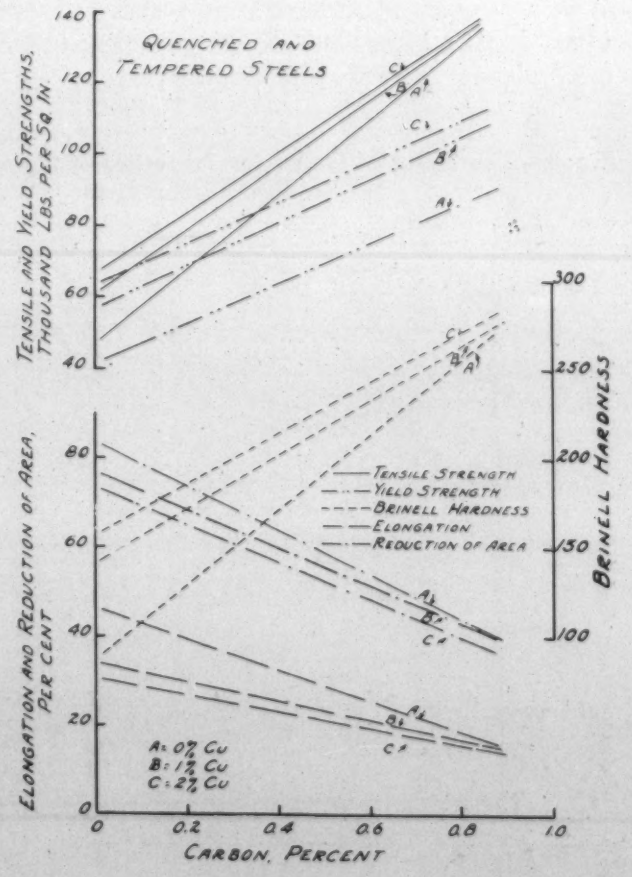


Fig. 2.—Properties of Quenched and Tempered Steels Containing 0, 1, and 2 Per Cent Copper with Reference to Carbon Content.

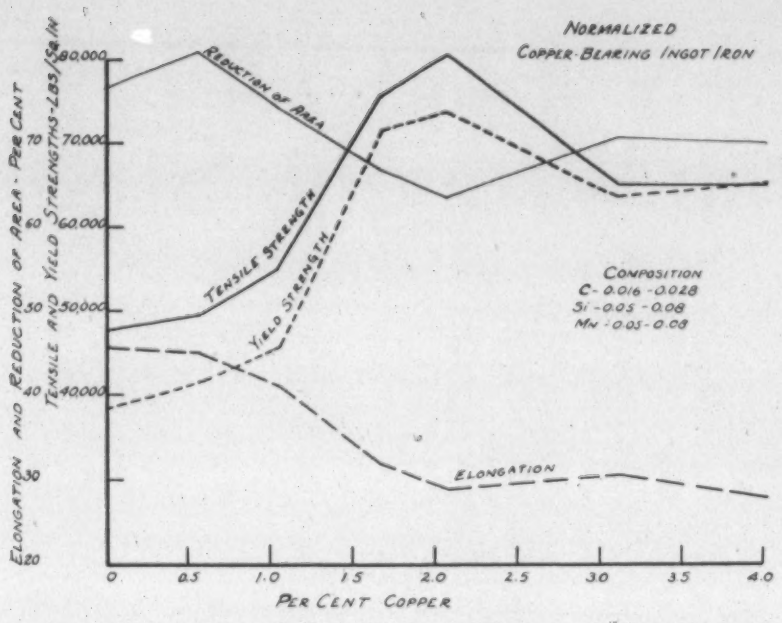


Fig. 3.—The Effect of Copper on Properties of Normalized Ingot Iron.

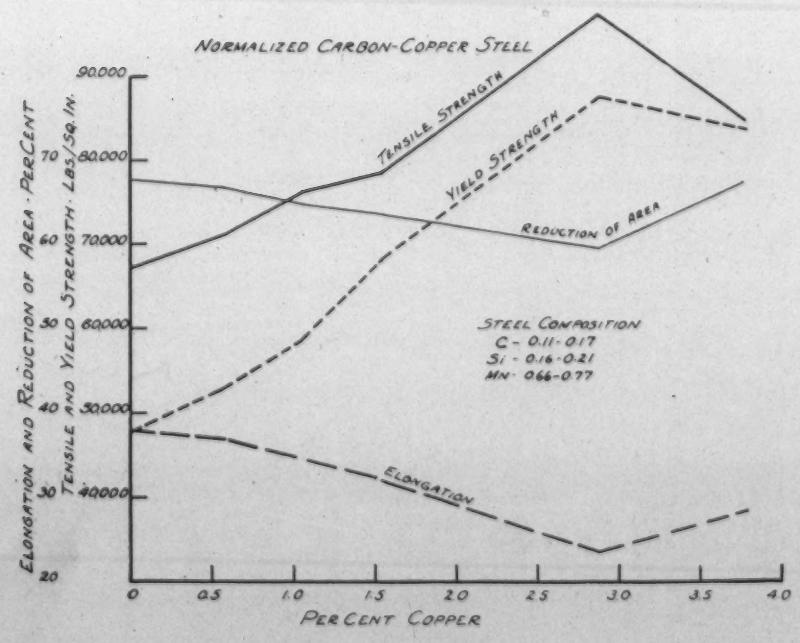
of carbon and its effect on loss of toughness is less, as is clearly brought out when properties of copper steels are compared with straight carbon steels of the same tensile strength. When, for example, normalized steels of 100,000 lbs. per sq. in. tensile strength are compared, the carbon content of the carbon steel, according to Fig. 1, will be about 0.47 per cent, that of the 1 per cent copper steel about 0.33 per cent, and that of the 2 per cent copper steel about 0.2 per cent, and their respective properties will be as follows:

	0.47 per cent Carbon Steel	0.33 per cent Carbon, 1 per cent Copper Steel	0.20 per cent Carbon, 2 per cent Copper Steel
Tensile Strength, p.s.i.	100,000	100,000	100,000
Yield Strength, p.s.i.	60,000	67,000	80,000
Brinell	188	195	196
Red. of Area, per cent	47	54	61
Elongation in 2 in., per cent	26	28	28

As shown by this comparison the increase in yield strength and toughness of the steel with copper is gradual and is unaccompanied by any change in Brinell hardness.

While Fig. 1 demonstrates the effect of copper in normalized steel, its effect in annealed steels or in water-quenched and drawn steels is somewhat different. In the annealed steels, for example, the first 1 per cent copper affects the properties in the same manner

Fig. 4.—The Effect of Copper on Properties of Normalized, 0.11-0.17 Per Cent Carbon Steel.



and to the same degree as 1 per cent copper in normalized steels, but with more copper up to 2 per cent the properties of the annealed steels remain practically unchanged. In quenched and drawn steels, the yield strength is improved greatly by copper. This can be noted in Fig. 2 where the properties of quenched and drawn steels are shown.

Further significant changes in properties occur when the copper content is extended above 2 per cent. In normalized steels, the rapid rise in tensile strength, beginning with somewhat more than 0.5 per cent copper, reaches a maximum value somewhere between 2 per cent and 3 per cent copper. More copper causes the strength of the steel to decline. With the decline in tensile strength the yield ratio rises rapidly, so that, in the neighborhood of 4 per cent copper, the yield strength is the same as the tensile strength.

The properties of normalized copper-bearing ingot iron containing copper up to 4 per cent are shown in Fig. 3.

Similar trends in properties are shown in Fig. 4 for normalized steel containing 0.11 to 0.17 per cent car-

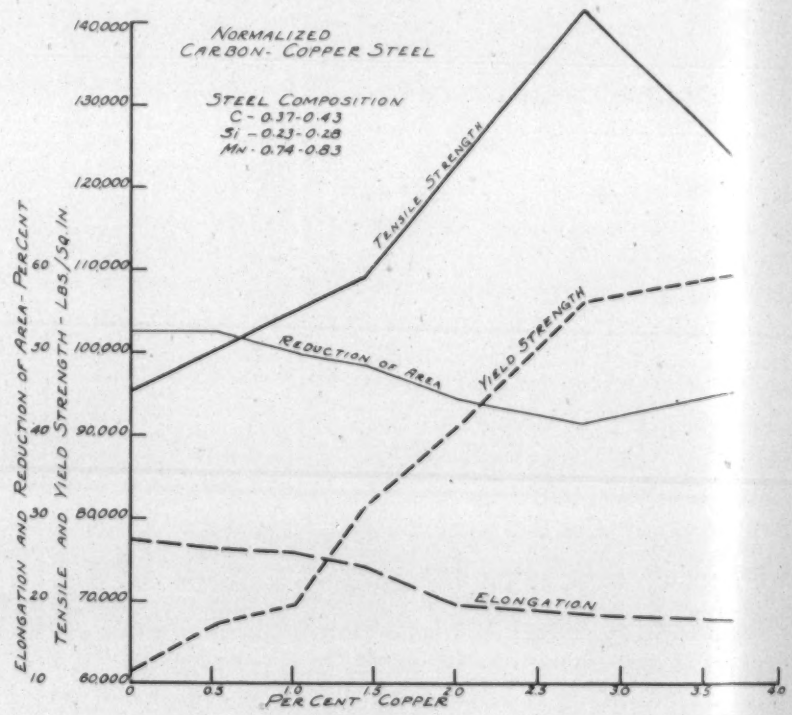


Fig. 5.—The Effect of Copper on Properties of Normalized 0.35-0.43 Per Cent Carbon Steel.

bon, and in Fig. 5 for normalized steel containing 0.35 to 0.43 per cent carbon. Each of these figures shows the strong effect of copper on properties when increased from 0.50 per cent to 2.0 per cent, then from 2 per cent to 3 per cent and finally from 3 per cent to 4 per cent. It appears that the knee in the tensile strength curve is shifted to higher copper contents by carbon.

The excellent elongation and reduction of area values for steels containing more than 2 per cent copper illustrate the remarkable ductile properties of copper steels.

For many uses of steel both static and dynamic ductility are important. Although the simple alloying of copper in steel decreases its ductility and toughness, for conditions of equal tensile strength or equal yield strength, copper steels are more ductile than plain carbon steels. It will be noted in Fig. 6 that the spaces between the curve for 0 per cent copper and those for 1 and 2 per cent copper widen noticeably toward the lower impact and the higher tensile strength values. The widening is in a direction to indicate decisively that, to obtain dynamic ductility in steels of high

strength, it is better to alloy the steels with copper than with carbon. These curves cover the full range of carbon from 0.02 per cent to 0.90 per cent for both the carbon steels and for the copper steels.

Since the presence of copper affects the yield strength of steel to a larger degree than the tensile strength, it is evident that, on the basis of yield strengths, the impact resistance of copper steels should show to even better advantage when compared with the impact resistance of carbon steels. This superiority is clearly shown in Fig. 7. Here the yield strength-impact curve for the plain carbon steels falls considerably below the curve for the 1, 2 and 3 per cent copper steels, which in turn is below the curve for the 4 per cent copper steels. It is remarkable that I per cent of copper should have such a profound effect upon the yield-impact relation of steel. It is equally remarkable that not until the copper content exceeds 3 per cent is this relation further improved.

Good dynamic ductility of steels does not always go hand in hand with good static ductility. For copper steels, however, this is the case. Thus in Fig. 8 the

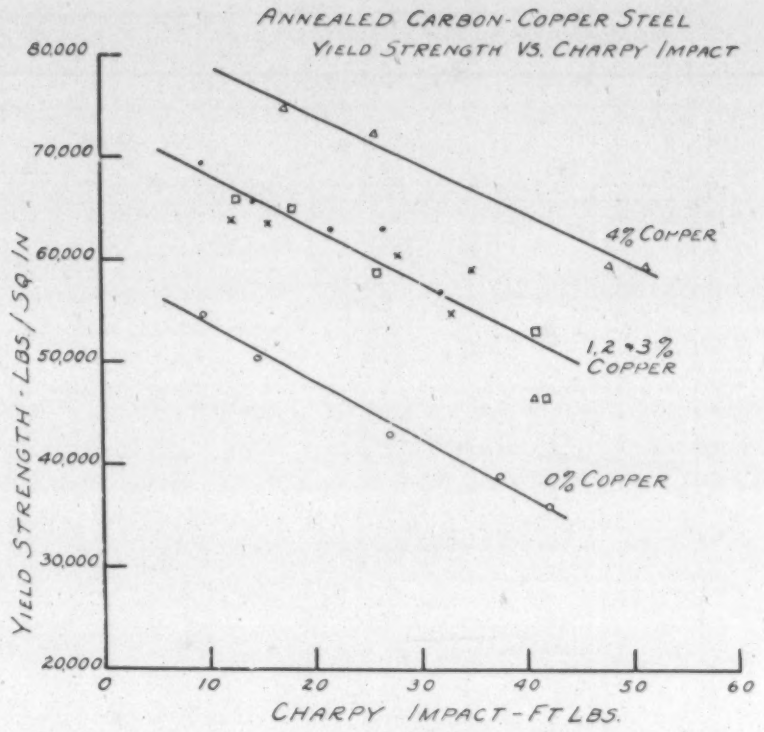


Fig. 7.—The Relation of Yield Strength to Charpy Impact Resistance of Annealed 0.02-0.43 Per Cent Steels Containing 0, 1, 2, 3, and 4 Per Cent Copper.

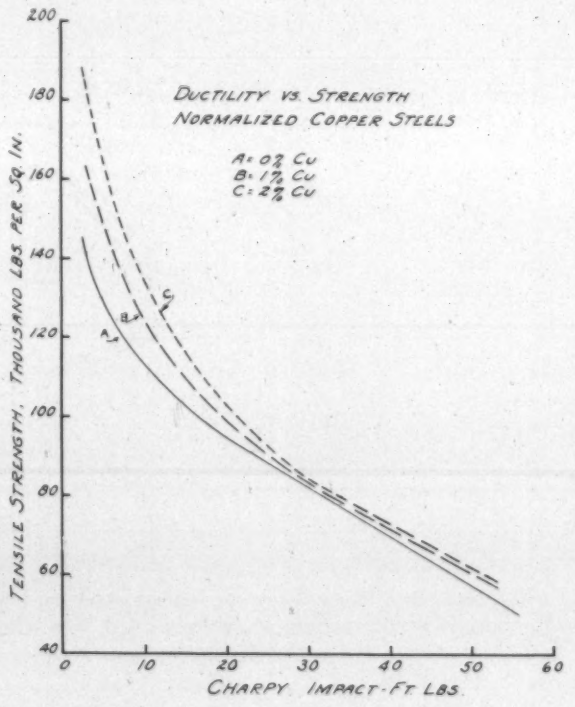


Fig. 6.—The Relation of Tensile Strength to Charpy Impact Resistance of Normalized Steels Containing 0, 1, and 2 Per Cent Copper.

yield strength-elongation curve for the plain carbon steels is below the curves for the 1, 2 and 3 per cent copper steels. The copper steels group themselves into those of 1, 2 and 3 per cent copper and those of 4 per cent copper with the better ductility again in evidence for the 4 per cent copper steels.

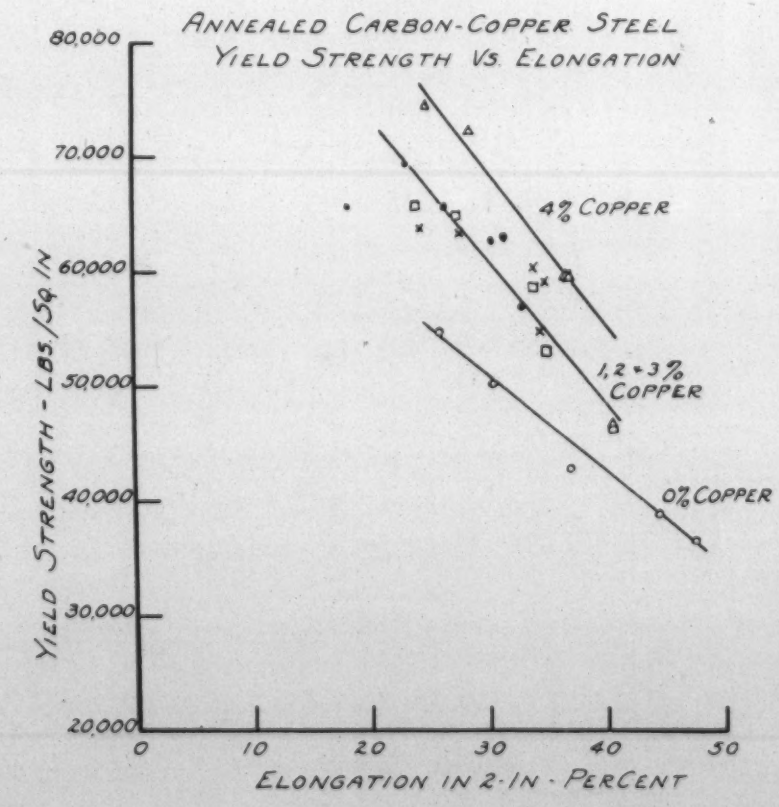
The above discussion of properties of copper steels is based upon data on bar stock, as the low cost, low alloy, high strength sheet steels are so much in the eye of the producers and consumers of steel. Examples of properties of 3/8-in. plate and of 19-gauge sheet rolled from steel containing 0.1 per cent carbon and 1 per cent chromium whose copper contents varied in small increments over the range from 0 to 1.5 per cent are set forth in the graphs to follow. These show that, while the presence of 1 per cent chromium has altered the base properties of the steels, the effect of copper, as described above for carbon steels, is not materially changed by the presence of another alloying element.

The tensile and yield strength properties of the normalized 3/8-in. copper-chromium steel plate are shown in Fig. 9. These properties are represented by the curves marked "normalized." The tendency for the tensile strength or the yield strength to increase with copper contents begins gradually, but continues at an accelerated rate.

The presence of 1 per cent of copper raised the tensile strength 6,000 lbs. per sq. in., and the yield strength 9,000 lbs. per sq. in., while 1.5 per cent copper increased each of these properties 20,000 lbs. per sq. in.

In this figure, along with the curves for normalized steels are the curves for steels that were normalized and then reheated for 3 hrs. at 930 deg. F. These latter curves are designated by the word "reheated." This treatment, generally known as "precipitating hardening," and to be described later, hardens and strengthens steels of certain copper contents. Both the tensile strength and yield strength curves rise steeply between 0.6 per cent copper, where precipitation hardening first becomes effective, and 1.1 per cent copper where the optimum effect is obtained.

Fig. 8.—The Relation of Yield Strength to Elongation of Annealed 0.02-0.43 Per Cent Carbon Steels Containing 0, 1, 2, 3, and 4 Per Cent Copper.



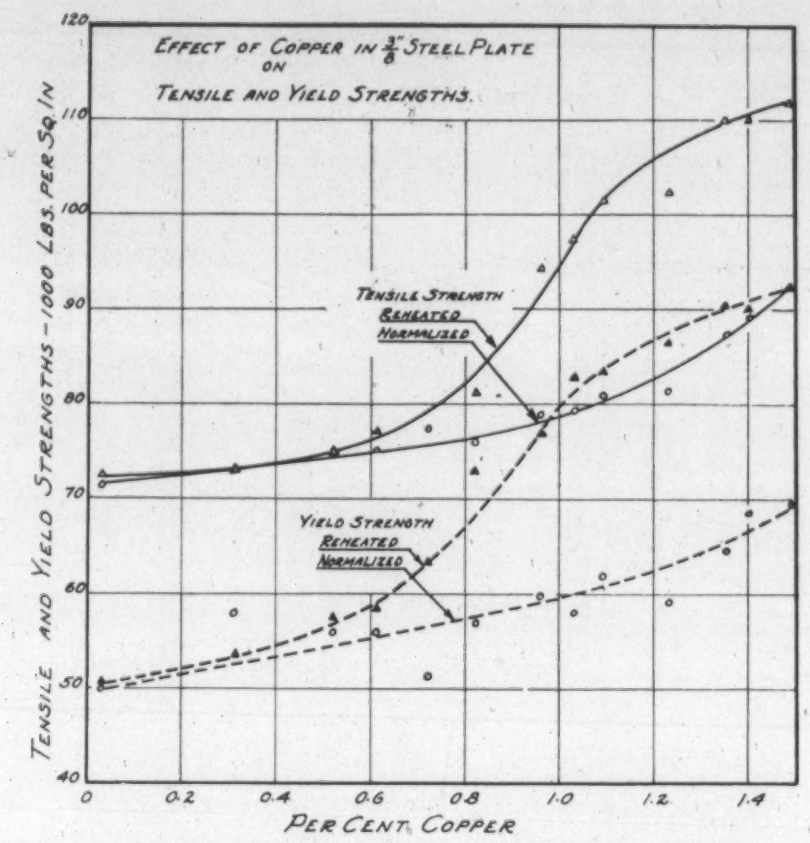


Fig. 9.—The Effect of Copper in 3/8-in. Plate on the Tensile and Yield Strengths of Normalized and of Normalized and Precipitation Hardened, 1 Per Cent Chromium, 0.1 Per Cent Carbon Steel.

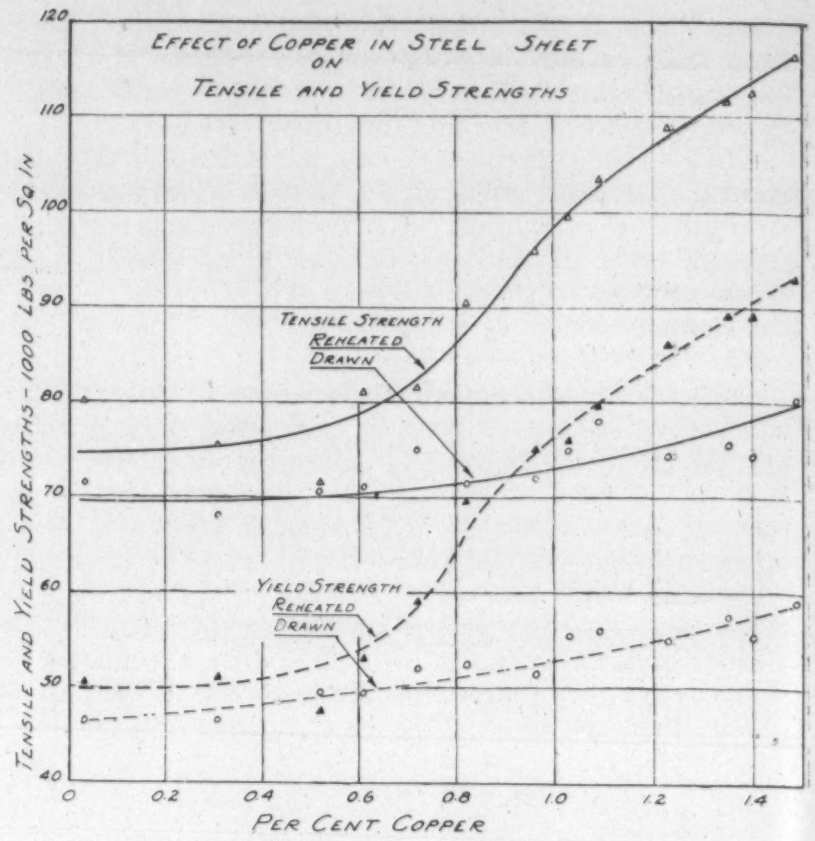


Fig. 11.—The Effect of Copper in 19-Gauge Sheet on Tensile and Yield Strengths of Normalized and Drawn and of Normalized and Precipitation Hardened, 1.0 Per Cent Chromium, 0.1 Per Cent Carbon Steel.

The precipitation hardening treatment effected an increase in strength of between 20,000 to 25,000 lbs. per sq. in.

The Brinell hardness, the reduction of area and the elongation for the normalized and for the precipitation hardened plate are given in Fig. 10. The Brinell hardness of the normalized steel gradually increased with copper, whereas both the reduction of area and elongation gradually decreased. The abrupt changes within the range of copper from 0.6 per cent to 1.1 per cent toward higher Brinell values and to lower reduction of area and elongation values which follow the precipitation hardening treatment are shown by the curves marked "reheated."

In these low carbon, chromium steels the use of copper had the specific action of improving the yield and tensile strengths without as much loss of ductility as would be produced were the improvements obtained by increasing the carbon content. With 1.5 per cent. copper, the yield and tensile strengths of the normal-

Fig. 10.—The Effect of Copper in 3/8-in. Plate on the Brinnel Hardness, the Elongation and the Reduction of Area of Normalized and of Normalized and Precipitation Hardened, 1.0 Per Cent Chromium, 0.1 Per Cent Carbon Steel.

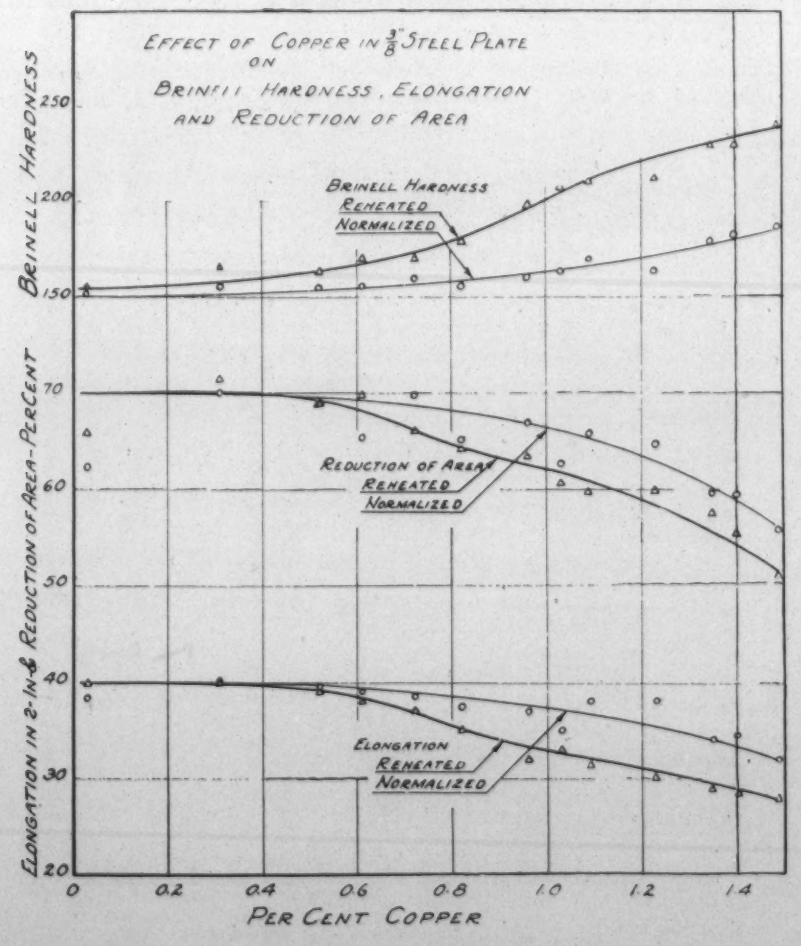
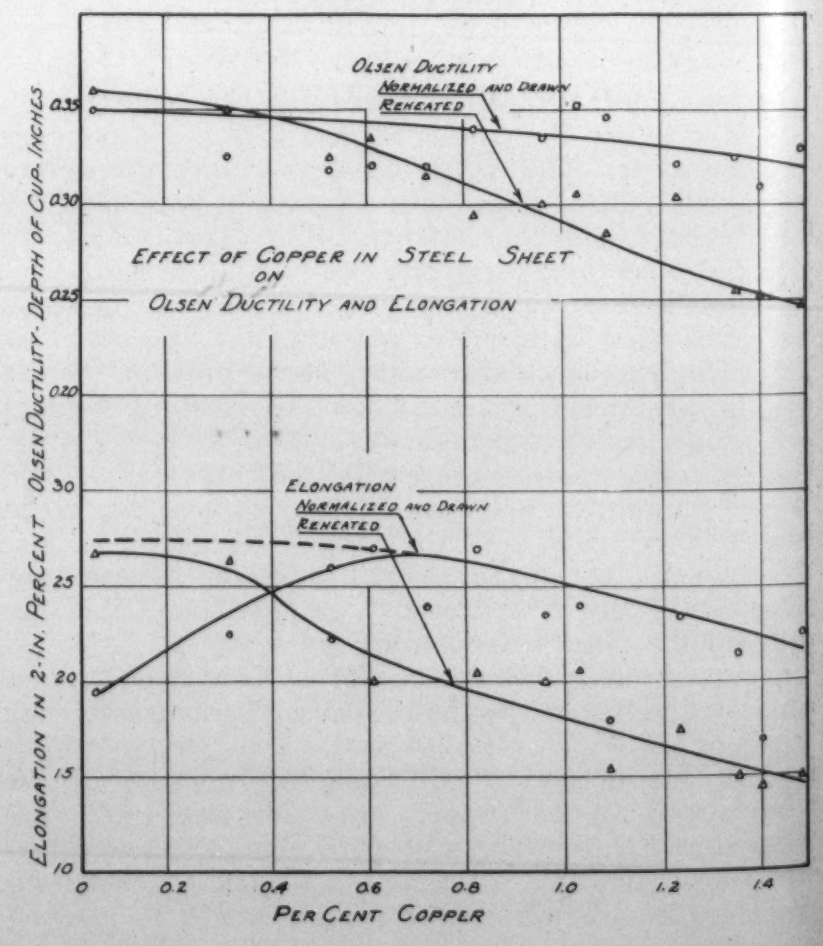


Fig. 12.—The Effect of Copper in 19-Gauge Sheet on the Olsen Ductility and the Elongation of Normalized and Drawn and of Normalized and Precipitation Hardened, 1.0 Per Cent Chromium, 0.1 Per Cent Carbon Steel.



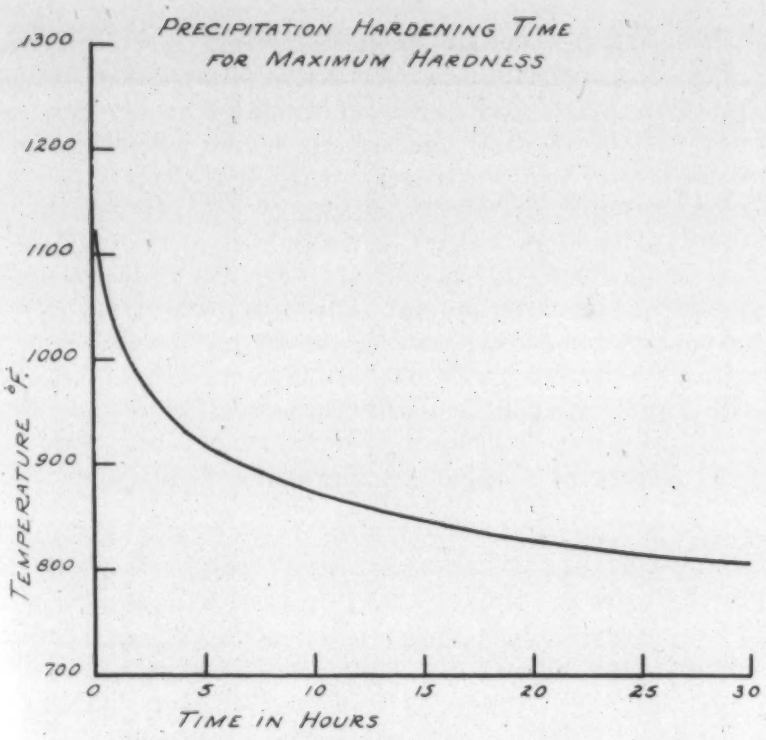
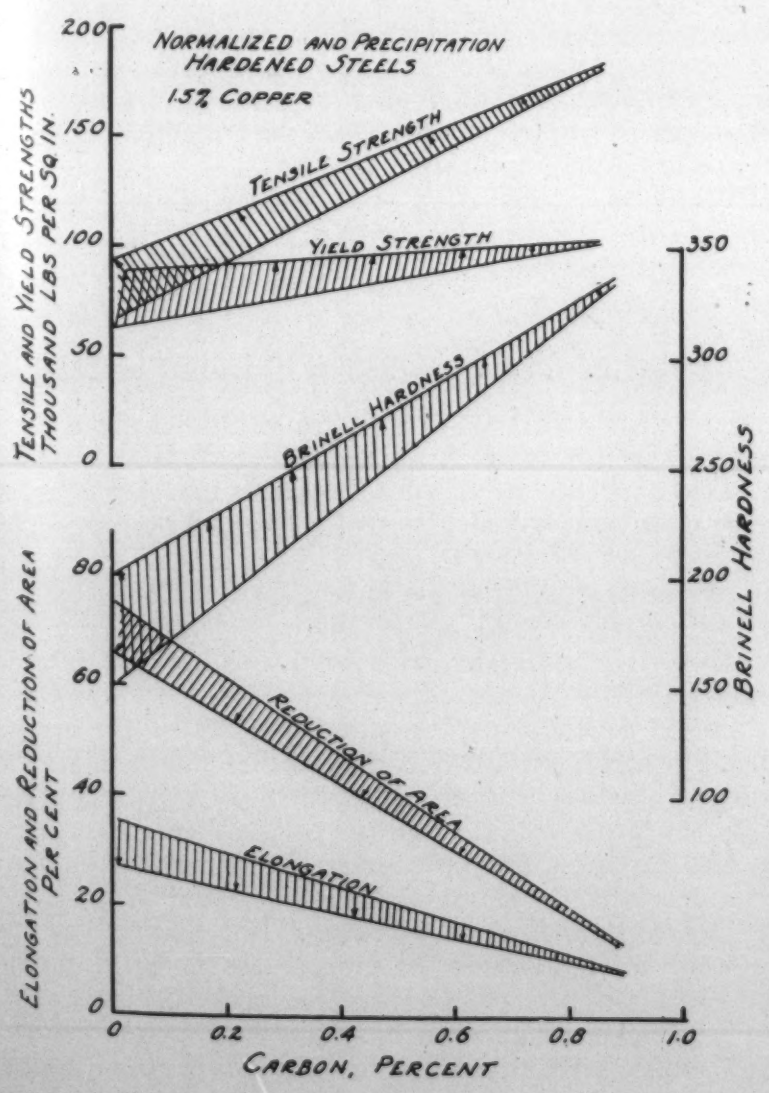


Fig. 13.—Time-Temperature Relation for Maximum Hardness Increase during Precipitation Hardening.

ized steels were raised 20,000 lbs. per sq. in., the Brinell hardness was increased 30 points, the reduction of area was lowered from 70 per cent to 50 per cent and the elongation was decreased from 40 per cent to 33 per cent. It is apparent that the strength of copper steels can be further augmented by the simple precipitation hardening heat treatment.

Somewhat analogous properties were obtained when the steels were rolled to sheet. Fig. 11 gives the tensile and yield strength values of a series of low carbon, 1 per cent chromium sheet steels containing copper. The sheets were normalized for 1 hr. at 1650 deg. F. Some of them were drawn 4 hrs. at 1200 deg. F. to remove the hardening effects which may accompany air cooling of such thin materials; others were given the precipitation hardening treatment for 3 hrs. at 930 deg. F. The strength of sheets that had been normalized and drawn increased continuously and at an accelerated rate as the copper content increased. The magnitude of effect of copper was slightly less in these tests with sheets than it was in the case of plates which were normalized. This was due to the softening which accompanied the 1200 deg. F. draw. The maximum increase in yield or tensile strength of steel containing 1.5 per cent copper was 11,000 to 15,000 lbs. per sq. in. for the sheet, compared wth 20,000 lbs. per sq. in. for the plate.

Fig. 14.—The Magnitude and Direction of Property Changes Brought about by Precipitation Hardening 1.5 Per Cent Copper Steels of Varying Carbon Contests.



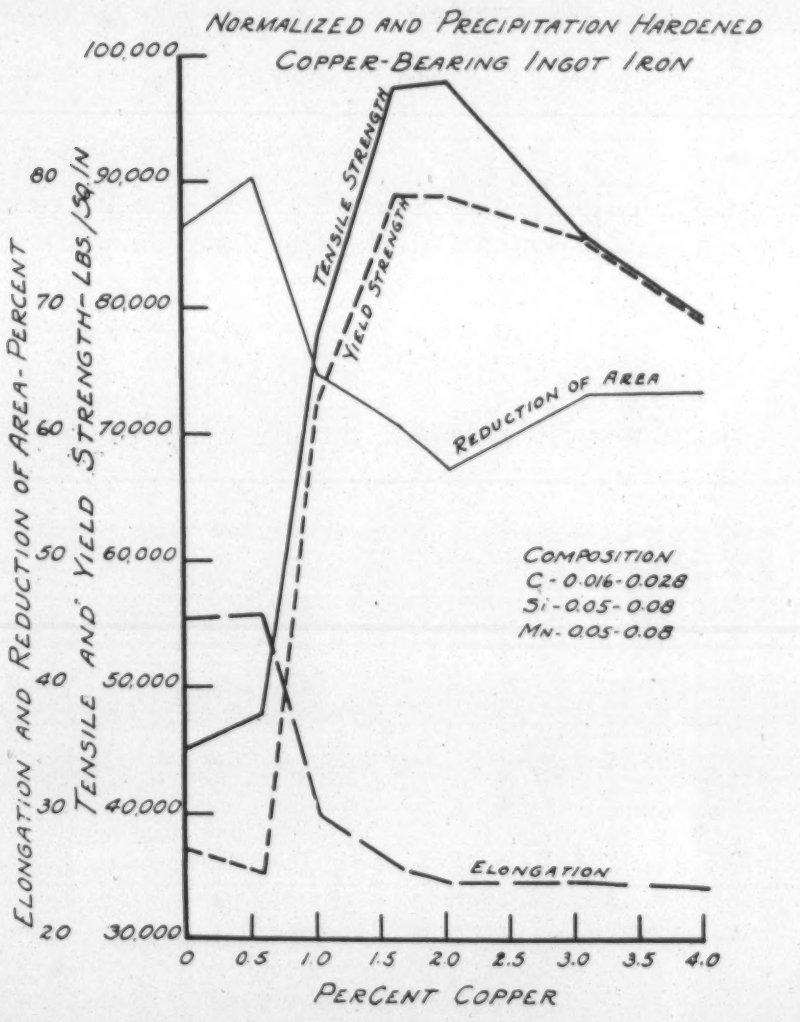


Fig. 15.—The Effect of Copper on Properties of Normalized and Precipitation Hardened Ingot Iron.

The precipitation hardening treatment was equally effective in increasing the strength of the sheet as it was with the plate.

The static ductility and the cold formability of normalized and drawn sheet are only slightly affected by copper, as shown by the Olsen ductility and elongation values given in Fig. 12. The normalized and drawn steels show but small reduction in either ductility or formability with copper. However, those steels which are precipitation hardened show large reductions in these properties when the copper content is above 0.6 per cent.

Both longitudinal and transverse sections of the normalized copper-bearing sheet could be bent through 180 deg. without cracking, indicating that the presence of copper has no bad effect on the bend qualities of sheet steel.

Further Increase in Strength by Precipitation Hardening

We have already pointed out that the strength of hot-rolled and of normalized steels containing above 0.6 and less than 4 per cent copper may be further increased by heating at from 750 to 1100 deg. F. The increase in strength results from precipitation hardening, made possible by the fact that copper remains in solution in the steel as it cools from the rolling or normalizing temperature, forming a super-saturated solution and then is precipitated when the steel is heated to a suitable temperature and held for a definite time.

Precipitation hardening may be accomplished by cooling the steel from the normalizing or hot-working temperature to the temperature range indicated and

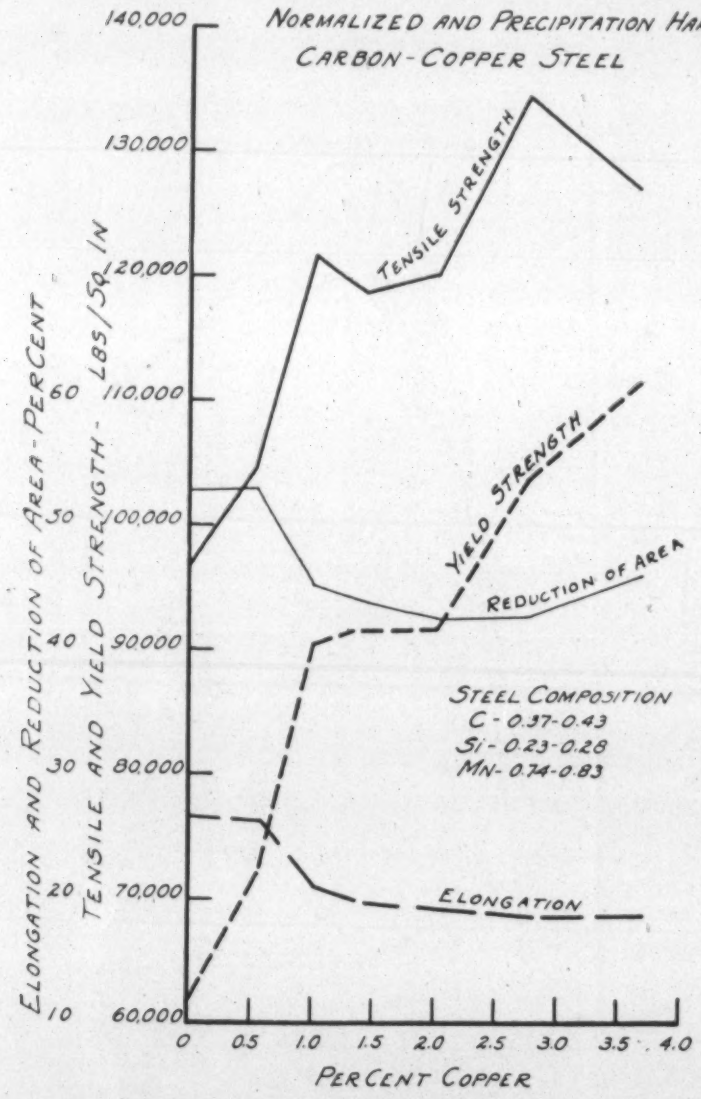


Fig. 16.—The Effect of Copper on Properties of Normalized and Precipitation Hardened 0.37-0.43 Per Cent Carbon Steel.

there arresting the cooling for the desired time, or it may be accomplished by reheating the steel and holding it at the desired temperature. The results are equivalent with either procedure. The time required to hold the steel at the precipitation hardening temperature to produce the maximum hardening effect for each temperature may be obtained from the curve shown in Fig. 13. The greatest change in properties of copper steels is obtained when the precipitation hardening temperature lies between 800 and 1000 deg. F.

Fig. 14 shows the changes brought about by precipitation hardening normalized steels containing 1.5 per cent copper with varying carbon contents. The width of the shaded areas shows the magnitude of the changes in properties and the arrows point in the direction of these changes. A steady decrease in the effect of precipitation hardening occurs with carbon until at 0.9 per cent carbon the effect is insignificant.

Figs. 15 and 16 show the diminishing effect of precipitation hardening with increasing carbon contents. They also show that the susceptibility to precipitation hardening is lower for steels with less than 1 per cent and more than 3 per cent copper.

Thus it is seen that copper steels may be further increased in strength by 20,000 to 30,000 lbs. per sq. in. by a simple heat treatment by holding the steel for 2-3 hrs. at the relatively low temperatures of 800 to 1000 deg. F. This is a most useful characteristic distinctive with copper steels.

Effect of Copper on Corrosive Resistance

It is general knowledge that the resistance of steel to atmospheric corrosion is considerably increased with copper contents above 0.20 per cent but that the increase in resistance tapers off as the copper contents increase above 0.20 per cent. Service and extended atmospheric corrosion tests have indicated that a few tenths per cent of copper may double or triple the atmospheric corrosion resistance of steel. Fewer data are available on the resistance to corrosion of steels containing more than a few tenths per cent of copper.

Various combinations of copper with other elements are being employed to enhance the atmospheric corrosion resistance of steels beyond what may be obtained with copper alone. Some examples of such compositions of low-alloy steels in commercial use are as follows in percentages:

C	Si	Cu	Ni	Cr	Mo	P
0.10	..	1.00	0.50	..	..	0.10
0.10	..	1.00	2.00	..	..	..
0.10	..	1.40	0.70	..	0.15	..
0.25	0.75	0.40	..	1.00	..	0.10
0.15	..	0.55	..	0.40	..	..
0.25	..	0.30	..	0.95	..	..

Of particular interest is the high-phosphorus content in several of these steels. The combination of copper and phosphorus for increased atmospheric corrosion resistance is noteworthy. It is especially significant in view of the fact that phosphorus in addition to improving the corrosion resistance, increases the strength of copper steels. This has recently been discussed in other accounts.[2]

While it is definitely established that copper increases the resistance of iron and steel to atmospheric corrosion, the results of submerged corrosion tests are not in good agreement.

Effect of Copper on Rolling Qualities of Steel

Copper in steel causes a characteristic surface checking in the hot worked material. The condition is intensified as the amount of copper increases, as the temperature at which the steel is rolled becomes higher, and as the time the steel is held in the soaking pit or in the heating furnace is lengthened. This effect is a surface effect and not a characteristic of the body of the steel as is the case in steel that exhibits hot shortness.

Unless precautions are taken to avoid it the surface checking may extend a considerable distance into the body of the steel, especially with high copper contents. This surface checking manifests itself to some degree on flat surfaces, but is most severe at edges that have been extruded or have not been subjected to the action of the rolls during hot-working. It is caused, we believe, by an enrichment of copper on the steel surface as a result of the removal of some of the iron at the surface by scaling, with a subsequent penetration of the copper enriched alloy of relatively low melting

point around the grains, near the surface, which are pulled apart when worked hot. No surface checking occurs in steel rolled below about 2000 deg. F., which is approximately the melting point of copper.

Experiments have shown that this surface checking can be avoided: (1) by heating the steel prior to hot working in a non-oxidizing atmosphere, (2) by hot-working the steel at a temperature below 2000 deg. F., or (3) by adding nickel to the steel to raise the melting point of the copper-rich alloy formed during the scaling. The amount of nickel required varies with the method of rolling, the temperature, and the length of time the steel is held in the heating furnace. Normally a quantity of nickel equal to one-third to one-half the coper present will suffice, but in severe cases more may be required. Cobalt is the only element besides nickel that we have found to have this beneficial effect.

Several plant trials in which nickel was employed to offset the surface checking caused by copper proved the value of nickel for this purpose. In one trial 1 9/16-inch plate was rolled from low carbon, 0.54 per cent copper, 0.50 per cent chromium steel and from a similar steel further alloyed with 0.50 per cent of nickel. The surface of the nickel-free plate was covered with tiny surface cracks while the surface of the plate that contained nickel was smooth and satisfactory.

In another instance, 0.35 per cent nickel was found to be sufficient to prevent surface checks in seamless tubes containing 1.0 per cent copper.

Shapes rolled from ingots containing 1 per cent copper and no nickel; 1 per cent copper and 0.14 per cent nickel; and third case 1.4 per cent copper and 0.7 per cent nickel. A beneficial effect was shown by as little as 0.14 per cent nickel and there was virtual absence of cracks where one-half as much nickel as copper was present.

(This paper was presented at a recent meeting of the A.I.M.E. at Youngstown.)

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[2] Gillett, H. W., "Phosphorus as an Alloying Element in Steel." METALS AND ALLOYS, Vol. 6, 1935, p. 280 to 283, and 307 to 310.

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EDITORIAL COMMENT

(*Continued from page A23*)

corrosion research is suffering seriously from the pressure that is put upon scientific workers to join in committee and similar types of work. Particularly mistaken appear to be some of the efforts designed to prevent "overlapping." Actually it is better that two men should carry out the same work unknown to one another than that they should spend so much time corresponding, coordinating, and apportioning the labor that finally it is carried out by neither. Personal contacts between different investigators have a value that can hardly be overestimated, and, where the investigators belong to different nationalities, the benefits for the world are not confined to the progress of science. But it must never be forgotten by those who organize cooperative gatherings—whether they be public conferences or private committees—that any time and energy given up to these things is time and energy taken from something else; and it must not be assumed that the "something else" may not possess greater value.

One can thoroughly sympathize with Evans, yet it seems to us that there is a way by which the benefits of joint action can be maintained without making committee work too vast a burden. When a man has reached such a position of experience and influence in a given field that he is sought as a member of every major committee having to do with that field, which may be a pretty wide one, it is very often indeed that he is sought partly for the sage counsel he can give, but partly also for the prestige of his name, and the chairman who appoints him knows it and hopes the appointee may sit in at the meetings once in a while, but he does not really expect much real work from this already over-worked old-timer. The real committee work falls on a few wheel-horses whose university or business connection justifies the official time they allot to the work and whose personal interest in the subject is great enough so that they are willing to put a good deal of their own time on the job.

Most committees have, however, a rather large proportion of those who cannot take very much more than a passive interest in the committee work at present, irrespective of how active they may have been in the period in which they were gaining the reputation that causes them to be wanted as members. Some autumn leaves of this sort can be borne, but too many of them approach really dead wood.

Now these old-timers, almost without exception, have younger men in their organizations who are doing, sometimes still under direction, but often pretty much on their own, the actual work in the field of any given committee. They still have their spurs to gain and they would welcome the chance to do the active committee work, getting advice and counsel from the older man as they need it. A committee largely made up of such youngsters, with a sprinkling of oldsters to give it balance, can go places and do things.

By having the youngsters attend a few committee meetings with the older men they are assisting, then act as their representatives in their absence, and finally be given full membership, the stage would be set for the continuity of the committee work, for relief for the older men and opportunity for the younger ones. Everybody would gain.

Two things operate against this; one is that the older man may fail to realize that his younger assistant has reached years of experience and discretion, for time flies so fast that he is prone to think of the youngster as still only a cub. The other is that the committee chairman hasn't guts enough to prune out the dead wood and graft in the young shoots. It isn't a bad plan to have a committee so organized, or reorganized if it started wrong, that there is definite rotation in membership or at least some rather definite time at which changes in membership are expected and an old member can retire gracefully of his own initiative or can be retired without hurting his feelings. A simple way, in the case of a large committee, is to have an executive committee which does the real work, whose tradition is not to keep exactly the same personnel for any extended period, and let the full committee advise and approve without having to join in all the deliberations. The figureheads can be harmlessly left on the main committee.

We are all for committees that do things and there are mighty few that wouldn't do more if they had some new blood.—H. W. G.

Effect of Thallium on the Freezing Point of Indium-Lipowitz Alloy

By SIDNEY J. FRENCH

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AS HAS BEEN PREVIOUSLY reported by the writer[1], the freezing and melting points of Lipowitz Alloy are markedly lowered by the addition of indium. An alloy composed of 81.9 per cent Lipowitz Alloy and 18.1 per cent indium has been found to freeze at 46.7 deg. C. and melt sharply at 46.9 deg. C. Since Lipowitz Alloy freezes at approximately 70 deg. C. and melts at approximately 72 deg. C., the respective points have been lowered 23 deg. C. to 25 deg. C., by the addition of indium. The alloy is easily prepared by adding the requisite amount of indium to molten Lipowitz Alloy since indium dissolves readily in this molten alloy at temperatures but slightly above the melting point.

As reported by the writer in METALS & ALLOYS, January, 1936, pages 22-23, the freezing and melting points of Lipowitz Alloy may also be lowered by the addition of thallium, though the lowering is much less than that produced by indium. An alloy composed of 6 per cent thallium and 94 per cent Lipowitz Alloy freezes at 66.6 deg. C. and melts at 68.6 deg. C.

Since indium and thallium each lower the freezing point of Lipowitz Alloy, it was considered possible that the addition of both metals might lower the freezing point below that obtainable with indium alone. Data were therefore obtained on the freezing curves of such alloys.

Lipowitz Alloy was first prepared from the purest C. P. metals obtainable, by melting together in a large test tube, bismuth, lead, tin, and cadmium in the respective ratios:—50:27:13:10. The alloy was heated to the melting point of the highest melting constituent and during the cooling process was constantly stirred to insure thorough mixing. The freezing and melting points of the alloy were determined by means of cooling and melting curves and were found to be 69.7 deg. C. and 71.7 deg. C. respectively.

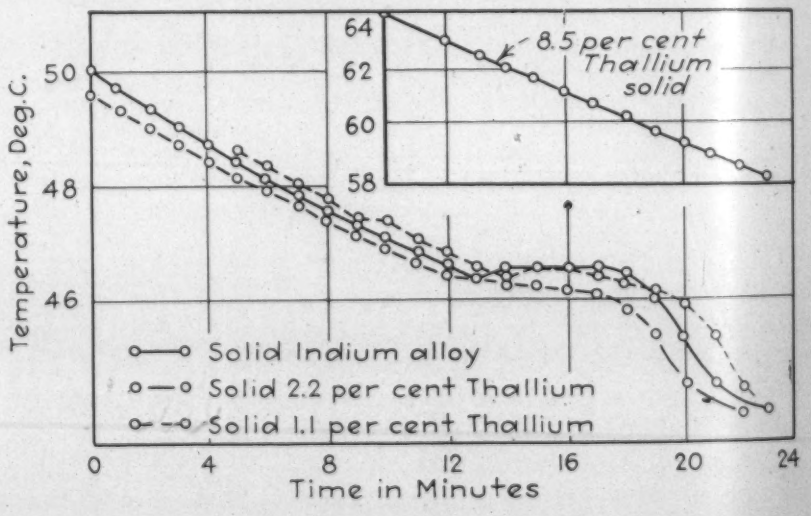
Indium-Lipowitz alloy was then prepared by adding the requisite amount of indium to a molten 15 gram sample of Lipowitz Alloy. The freezing point, determined by means of cooling curves was found to be 46.5 deg. C., the alloy freezing sharply at that temperature.

All determinations were carried out by placing the alloy in a thin walled test tube which was suspended in a water bath of 800 c. c. capacity which was in turn surrounded by an air bath. The water was stirred with a motor driven stirrer. The thermometer, which was placed with the bulb in the alloy and was used to stir the molten alloy with, was compared with a Bureau of Standards certified thermometer and showed an average deviation of 0.2 deg. C. and a deviation of 0.1 deg. C. at the freezing point of the indium-Lipowitz alloy.

Sufficient thallium, accurately weighed, was added to the molten indium-Lipowitz alloy to give an alloy containing 1.1 per cent thallium. The alloy was heated to the melting point of thallium and stirred. Cooling curve determinations were then made on the alloy. The final freezing temperature was the same as that of the indium-Lipowitz alloy but the curve showed some irregularities, indicating the solidification of some ingredients above the final freezing temperature. Stirring evidence likewise indicated some solidification above the final freezing temperature.

Next, an alloy containing 2.2 per cent thallium was prepared by adding the requisite amount of accurately weighed thallium to the previous alloy. This alloy also had the same final freezing temperature as the indium-Lipowitz alloy (46.5 deg.) but was definitely pasty at 47 deg. C.

The illustration shows cooling curves for the three alloys. It is to be noted that the indium-Lipowitz alloy yields a regular curve with a definite horizontal portion at the temperature of solidification. The alloy is not solidified when the temperature of solidification is first reached but only after remaining at that temperature for several minutes. On the other hand, the alloys containing thallium solidify at an earlier time interval, and show little or no horizontal portions in their curves.



An alloy containing 8.5 per cent thallium was prepared in a similar manner. The alloy became pasty at 60.5 deg. C. and was completely solid at 59.4 deg. C. There was no marked flattening of the curve. The inset in the illustration shows the cooling curve for this alloy.

It seems evident from these results that alloys freezing below 46.5 deg. C. cannot be obtained by adding thallium to the indium-Lipowitz alloy. However, alloys melting below this point might possibly be obtained by altering the proportions of the metals used. In any event it seems likely that the amount of the lowering would be small.

Reference

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Recent Developments Affecting the Testing Society's Specifications for Steel Castings—III

Tapping a Basic Open-Hearth Steel Heat for Castings. (Courtesy of General Steel Castings Corp.)

By R. A. BULL

Consultant on Steel Castings, 541 Diversey Parkway, Chicago

Concluded from the February Issue

Influence of Composition on Weldability—Problem of Several Phases

THE SPECIAL A.S.T.M. COMMITTEE that developed the new specifications for carbon steel castings for miscellaneous industrial uses (A180-35T) was requested in 1935 to present its ultimately formulated ideas regarding requirements for establishing the proper chemical composition of cast steel to be welded. This applied chiefly to fusion fabrication, for which method of manufacture increasing tonnages of steel castings are being used. The committee thus far has presented no recommendations regarding the matter.

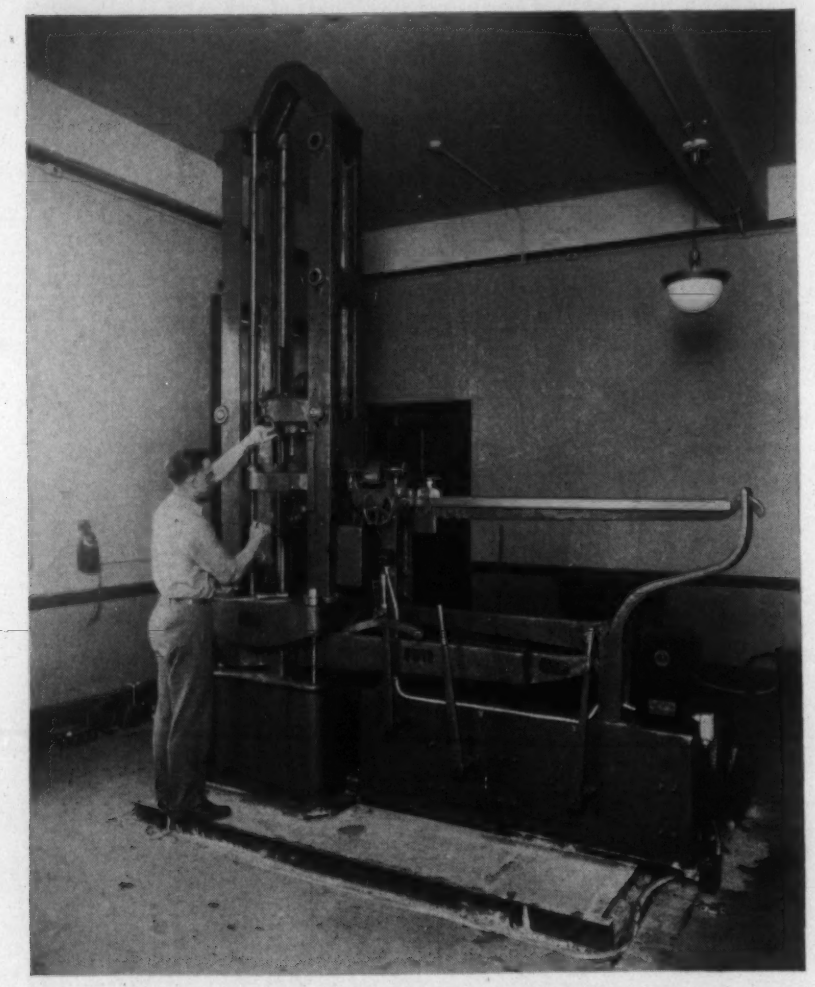
The problem appears to have three phases: One related to obtainable properties in the weld-metal and in the adjoining zone, when welding is contemplated for the repair of defects in carbon steel castings; another phase related to obtainable properties in the weld-metal and in the adjoining zone, when welding is contemplated for joining carbon steel castings to other cast or wrought parts for fabricating purposes, and when the nature of the assemblage would permit heat treatment for the relief of the stresses developed by welding; and a third phase related to obtainable properties in the weld-metal and in the adjoining zone, when welding is contemplated for fabricating purposes of the kind just mentioned and when the assemblage would not be such as to permit heat treatment for the relief of the stresses developed by welding. In the first case (weld-repairing), obviously heat treatment may invariably be applied for relieving stresses set up by the fusing operation.

It was realized at the start that difficulty would be experienced in attempting to develop the desired purchasing requirements, because of the existing differences of opinion held regarding grades of steel that can and cannot be effectively welded. It is well known to most metallurgists that, while equipment, amperages, voltages, gas pressures, rods, etc., enter into this matter, welding technique itself is an enormously important factor. (It is lessened, of course, when welding is done mechanically on a production basis, as the result of intelligent study given by competent engineers.) Because so many factors are involved in the effective application of a process that recently has experienced very rapid development by means of two distinct methods of producing the required heat, it is natural that there should now be differing opinions regarding the grades of metal that can be welded satisfactorily.

Unless it were indicated clearly that the significance of this specification problem is related mainly to fusion fabrication, some persons might conclude that the repair of defects is chiefly involved. Misunderstandings might readily prevail among engineers

who are not conversant with the rapidly growing use of cast steel components of welded assemblages. In several articles, published during the last ten years, the present writer has pointed out (without having any right to claim originality for the conception) that, when carefully analyzed, the functions of the welder and the steel founder primarily are found to be complementary rather than competitive.

The existence of this technical relationship is becoming increasingly apparent. The men who separately are engaged in the welding and founding branches of modern industry each have very good reason to cooperate with the individuals in the other



The Conventional Tension Testing of Cast Steel. (Courtesy of Sivyer Steel Casting Co.)

branch. The manufacture of numerous kinds of industrial metal parts can now most economically and otherwise satisfactorily be accomplished by welding steel castings to rolled steel parts. Intelligent discrimination is being exercised in forming certain simply designed portions of structures from commercial wrought steel shapes, and joining them to such steel castings as represent intricate portions of the same structures. While no competent welding expert would regard it as economical on a production basis to form by welding many a complicated part that may readily be made in the steel foundry, there is no intelligent foundryman who would truthfully assert that a steel casting can be produced as cheaply as a portion of many a commercial rolled shape, given the same dimensional limitations (including moderate casting length) in each case.

Of course the fabricating problem is far from being one merely of cheap production. The highly important factor is that of stress resistance in the weld-metal and in the adjoining zone. It is the latter phase of the problem that is brought most significantly into the discussion of A.S.T.M. specifications.

More Data Needed on Effects of Elements Always Present

There is no reason to doubt that the details of steel welding practice will become sufficiently understood within the next five years to result in eliminating many differences of opinion now held by men regarded as having considerable knowledge of the subject. Unfortunately one can now get contradictory answers to some questions which relate to the matter and appear to the casual inquirer lacking a metal-consciousness to be much simpler than they are. But common-sense consideration by men who have a fair understanding of metal characteristics enables them to realize that many repeated tests of very difficult nature must be made before one may correctly attribute good or bad weldability solely to the given percentage of a single one of the several associated elements.

On apparently good grounds, high carbon content generally is now regarded as deleterious in steel contemplated for welding. What is the proportion that we should consider as high from this standpoint? In some quarters prejudice exists against a content that exceeds 0.30 per cent. Many persons who believe themselves technically justified would set the limit at 0.35 per cent. In most cases the reliance on a maximum proportion of carbon in the steel is expressed without qualification covering any of the other elements in the composition. Has a sufficient number of properly made tests been conducted to justify either of these opinions?

What about the content of silicon, as influencing weldability in conjunction with varying proportions of carbon? Until recently a number of welding engineers apparently felt justified in objecting to more than a very moderate amount of silicon in cast steel to be welded. But certain grades of low alloy-steel that are characterized by high silicon percentages are now being welded with demonstrated success.

How does such an amount of manganese as 0.90 per cent affect the welding job, compared with 0.65 per cent; when—let us say—the carbon and silicon contents, respectively, are 0.27 and 0.35 per cent?

Is fusion accomplished better by means of gas than by means of the arc, when the material consists of carbon cast steel averaging 75,000 lbs. per sq. in. tensile strength, having a given composition that is normal for that material? Does the welding process alone result in any significant difference in physical properties of cast steel having any given composition, when suitable welding rods and other important factors (voltages, amperages, pressures, etc.), are provided in each case?

What differences in chemical composition ranges of cast steel should be established for fusion fabrication when the material is not to be heat treated for relieving weld-stresses, as compared with material that is to be so heat treated? (There seems to exist no serious argument regarding the wide temperature range of the heat treatment that will relieve the stresses produced by welding.)

Differing questions to queries of the kind suggested probably would be made today by many welding engineers who have no inclination to deceive the questioner. To some extent the answers would differ because the formulation of opinions on any debatable subject frequently is the result of the individual's own experience.

Now it is obvious that the experience of many welding experts has been chiefly with rolled steel, and

that the greater part of such experience has been confined to the carbon grades. Such material differs in chemical composition with the ordinary carbon grades of cast steel. This fact is not universally understood. One would not be apt to find ordinarily in a rolled carbon steel channel or plate taken from regular warehouse stock as large a total amount of manganese and silicon as 1.25 per cent. But such a total amount of these deoxidizing elements would not be peculiar in the steel foundry's regular product having the same percentage of carbon as a wrought part under consideration. It is conceivable that this circumstance might have some influence in respect to weldability; as for example, the need for stress-relief after fusion.

Stress-Relief and Its Adaptation to Alloy-Steels

Of course the problem now facing steel founders and welders when trying to determine the good or bad influence of any element in the chemical composition is much greater than that affecting merely the grades of carbon steel used for the general line of industrial and railroad applications and the several grades of alloy steel which can be used to meet the single set of high strength requirements in the new railroad steel casting specifications. Up to this time the largest amount of welding fabrication in which steel castings have been used has been confined to carbon steel. But this condition of affairs is noticeably changing; so that many interesting structures are now being made by fusing a number of low alloy grades of wrought steel to similar varieties of cast steel.

A well-known, competent welding consultant recently pointed out that "weld-metal will behave precisely the same as any unwelded parent metal, provided it has identical chemical and crystalline qualities, the same mechanical treatment, the same 'age,' the same kind, degree and location of residual stresses, and discontinuities which are identical in degree and location. But such a condition is, to say the least, improbable * * * * A weld is a joint between pieces of metal which may be better or worse than the metals

Large Cast Steel Block Prepared for Examining Internal Structural Condition after Experimental Heat Treatment. (Courtesy of Michigan Steel Casting Co.)

Tapping an Alloy Steel Heat in the Foundry. (Courtesy of Sivyer Steel Casting Co.)

joined, but it is never identical with them." Little reflection is needed to bring the realization that these statements must be true. The extent to which a given proportion of a certain element influences the physical properties in steel used as a casting, a forging, or a rolled part, might be greater or less when the metal has been deposited under the arc or the gas flame.

It seems highly probable that a very large number of chemical compositions are satisfactorily weldable, when heat treatment for stress relief can be applied. There is no denying the fact that alloy steel is much more "temperamental" than is carbon steel. That is to say, the former is vastly more susceptible to improvement or to injury as the result of a very high temperature (beyond that to which parts ordinarily are subjected in service). It becomes extremely important, when welding each of most alloy steels used for castings either for fusion fabrication or for the repair of casting defects, to use the annealing oven as a medium for the relief of stresses set up by the heat in the welding zone and in the adjacent locations.

It happens that by far the largest number of composition grades of alloy cast steel contain relatively small amounts of carbon. It is well known that they depend for their significant physical properties on special elements. It is probably correct to say that the chief present basis of general agreement regarding undesirable weldable compositions for steel rests on moderately high carbon content. This circumstance minimizes the extent of the welding composition problem for those who happen to be chiefly interested in carbon steel. If we may assume that further advancement of welding procedure will never justify a relatively high percentage of carbon in the composition, the product of the steel foundry is not likely in the future to be handicapped greatly by that circumstance. And if it should be ascertained that, with a moderately low carbon content, most of the score or more of justly favored composition grades of low alloy cast steel can be satisfactorily welded if they are subsequently heat treated for stress-relief, the problem will become relatively simple, so far as welding fabrication

involving steel castings is concerned. Fortunately the evidence thus far points in that direction.

Certainly most of the carefully assembled data that have been reported indicate that heat treatment for stress-relief is highly desirable for all low alloy grades of steel commonly used for castings that have been welded. It seems reasonable to predict that, where the structure is such as to prohibit such heat treatment, little opportunity will be afforded for joining alloy steel castings to other steel parts. While the condition usually developed by peening a weld probably is better than that which would otherwise be typical of the deposited material, such mechanical treatment cannot be expected satisfactorily to take the place of an annealing furnace.

The matter of chemical composition as related to weldability has been discussed periodically for some time in several A.S.T.M. committees that are responsible for developing steel casting specifications. Undoubtedly some safeguarding clauses would be helpful to certain consumers. The desirability of determining accurate information before placing the stamp of approval on designated grades of cast steel that can be welded satisfactorily may be appreciated by realizing some of the circumstances which the author has attempted to explain. The state of present knowledge indicates that, for the present, the regulation of practices in respect to steel castings may be most feasible if it is confined to the allowable percentage of carbon and to the use of the annealing oven for relieving weld-stresses in specified grades of metal.

Celebrating Aluminum's 50th Anniversary

UNDER the auspices of The Electrochemical Society a dinner, in commendation of the 50th anniversary of the discovery of the electrolytic production of aluminum by Charles M. Hall, was held in the Starlight Roof of the Waldorf-Astoria Hotel in New York, on the evening of Feb. 17. Members and officers of the society, members of the American Institute of Mining and Metallurgical Engineers, members of the aluminum industry and directors of research for many important industries were present. At the head table there were included among the honored guests, eight of the fifteen Perkin Medalists, since the dinner celebrated not only the 50th anniversary of Mr. Hall's discovery, but also the 25th anniversary of the award to him of the Perkin Medal.

Presiding at the dinner was James H. Critchett, of the Electro Metallurgical Corp., New York, president of the society. Dr. F. C. Frary, a past president of the society and director of the Aluminum Research Laboratories, was toastmaster. There were three chief speakers. Dr. F. M. Becket, vice-president of the Electro-Metallurgical Corp., as well as a past president of the society, talked on "Fifty Years' Progress in Research." He is also a Perkin Medalist. "Aluminum in Transportation" was discussed by Alexander Klemin of the Guggenheim School of Aeronautics, and Homer Johnson, a Cleveland attorney and a schoolmate of Mr. Hall, gave personal reminiscences. Arthur V. Davis, chairman of the board of the Aluminum Co. of America, stressed the debt which the entire industry owes to Hall and his invention.

Phosphorus as an Alloying Element in Low Carbon, Low Alloy Steels—III

An Experimental Study

By C. H. LORIG and D. E. KRAUSE

Metallurgists, Battelle Memorial Institute, Columbus, Ohio

Concluded from the February Issue

Corrosion

IT IS CHARACTERISTIC of steels with the higher P contents to acquire a uniform rust coating in the early stages of exposure, while those of ordinary P content start to rust in a patchy fashion. The early attack appears to be somewhat more rapid in the higher P steels. The rust coating upon the high P steels is of a more protective nature than that upon low P steels and the attack slows down at a faster rate in the later stages of exposure.

The behavior of the Cu-P steels studied was quite in line with the expectations from the early observations of Storey and the later ones of Kendall and Taylerson which have previously been discussed in these columns.[1] It is of particular interest to note, however, that even without copper, increase in P decreases the loss by corrosion after a year's exposure, and that this holds in both straight P, Cu-P and Ni-P steels, as Table 12 shows.

Table 11. Physical Properties of Rolled and Annealed 22 Gage Steel Sheet.

Alloy No.	Treatment**	Composition, % * P	Cu	Other Alloys	Tensile Properties: Ultimate Strength, p.s.i.	Yield Strength, p.s.i.	Elongation, % in 2 in.
45	3	0.27			63,000	42,600	22
	4	0.27			62,000	42,000	23
	6	0.27			63,400	43,500	38
48	3	0.26	1.4		68,000	57,500	24
	4	0.26	1.4		75,200	68,000	18
	6	0.26	1.4		83,500	79,000	17
51	3	0.25	1.5	0.26 Mo	77,000	67,000	24
	4	0.25	1.5	0.26 Mo	84,500	81,000	17
	6	0.25	1.5	0.26 Mo	93,000	88,000	16.5
54	3	0.25	1.4	0.60 Mo	81,000	69,300	21
	4	0.25	1.4	0.60 Mo	91,000	85,500	19
	6	0.25	1.4	0.60 Mo	100,000	94,500	17
57	3	0.27	1.5	0.54 Cr	66,000	48,000	24
	4	0.27	1.5	0.54 Cr	81,000	75,000	19
	6	0.27	1.5	0.54 Cr	90,000	83,000	17
60	3	0.28	1.4	0.20 Zr	70,000	59,000	25
	4	0.28	1.4	+.24 Si	76,700	70,400	22
	6	0.28	1.4		85,000	78,000	15
63	3	0.25	1.5	0.19 V	72,500	63,000	21
	4	0.25	1.5	0.19 V	84,000	78,000	17.5
	6	0.25	1.5	0.19 V	96,000	88,000	15

* The steels were aluminum treated. See Table 4 for full composition. [METALS AND ALLOYS, February, 1936]

** Treatment (3)—Rolled under 1250 deg. F., anneal 1450 deg. F. 1 hr., furnace cool.

(4)—Rolled under 1250 deg. F., anneal 1250 deg. F. 5 hr., furnace cool.

(6)—Normalized by air cooling from 1750 deg. F. (½ hr. at 1750 deg. F.) followed by 50 per cent reduction in gage by rolling below 1250 deg. F., followed by annealing 5 hr. 1250 deg. F., furnace cool.

It would appear that, in atmospheric corrosion, phosphorus itself, and not solely the Cu-P combination, is of value, though of course that combination is the outstanding one for the purpose. A year's exposure is insufficient to allow definite conclusions as to corrosion resistance and the tests will have to proceed much further before final conclusions can be drawn. It seems definitely indicated, however, that high P will at least produce no bad effects upon resistance to atmospheric corrosion.

Table 12. Effect of 6 and 12 Months' Exposure to the Atmosphere at Columbus, Ohio, on the Corrosion of Phosphorus-Bearing Sheet Steel.**

Specimen	P %	Other Elements,* %	Weight Loss: Grams 6 months	Grams 12 months	Grams per sq. in. 6 months	Grams per sq. in. 12 months
1	0.016	.....	1.46	2.61	0.085	0.152
3	0.01	0.5 Ni	1.11	2.39	0.054	0.116
2	0.06	.....	1.34	2.52	0.065	0.121
4	0.06	0.5 Ni	1.07	2.35	0.052	0.114
5	0.10	.....	1.15	2.33	0.056	0.113
6	0.10	0.5 Ni	1.10	2.18	0.053	0.106
7	0.19	.....	1.14	2.12	0.055	0.103
8	0.19	0.5 Ni	1.09	1.98	0.053	0.096
9	0.29	.....	1.07	1.87	0.052	0.091
10	0.29	0.5 Ni	1.01	1.74	0.049	0.084
11	0.49	.....	1.07	1.64	0.055	0.084
12	0.76	.....	0.98	1.63	0.051	0.083
13	1.07	.....	0.95	1.46	0.049	0.075
15	0.45	0.54 Ni	1.01	1.68	0.052	0.086
16	0.72	0.54 Ni	0.92	1.38	0.047	0.071
17	1.00	0.54 Ni	0.88	1.40	0.045	0.072
19	0.02	0.31 Cu	1.22	2.60	0.062	0.133
20	0.05	0.31 Cu	1.21	2.35	0.062	0.120
21	0.26	0.31 Cu	1.08	1.90	0.055	0.098
22	0.43	0.31 Cu	1.09	1.70	0.056	0.087
23	0.70	0.31 Cu	0.95	1.41	0.048	0.072
24	0.94	0.31 Cu	0.86	1.32	0.044	0.068
27	0.027	1.04 Cu	1.39	5.45	0.071	0.279
28	0.11	1.04 Cu	1.12	2.08	0.057	0.107
29	0.31	1.04 Cu	1.09	1.87	0.056	0.096
30	0.47	1.04 Cu	0.86	1.60	0.045	0.082
31	0.71	1.04 Cu	0.84	1.28	0.043	0.066
32	0.96	1.04 Cu	0.81	1.14	0.042	0.058
33	0.96	1.04 Cu; 0.53 Cr	0.92	1.38	0.047	0.071
35	0.15	0.83 Cu	1.09	1.95	0.056	0.100
36	0.31	1.66 Cu	1.06	1.66	0.054	0.085
37	0.60	3.2 Cu	0.86	1.32	0.044	0.067
38	0.88	4.7 Cu	0.77	1.29	0.039	0.066

* Alloys not aluminum treated. Carbon content about 0.02, manganese 0.07, silicon 0.03, and sulphur 0.02 per cent.

** Exposure on one side only. Specimen dimensions: 1—2½ in. x 6⅞ in.; 2 to 10—3 in. x 6⅞ in.; 11 to 38—3 in. x 6½ in.

In corrosion in water, the behavior does not appear to be notably affected by raising the phosphorus. Several series of specimens totally immersed in sea water at Miami Beach, Fla., failed to show any clear tendency as to effect of P, between 0.02 and 1 per cent, upon alloys without Cu or Ni and those with 0.5 per

cent Ni or 0.3 per cent or 1 per cent Cu. Marine growths upon the specimens tended to protect them from corrosion and variable amounts of these growths produced such irregular results that true trends were not established in this test.

Intermittent immersion in hot water (140 deg. F.) for 21 days gave the results shown in Table 13.

Table 13. Corrosion of 22-Gage Phosphorus-bearing Sheet Steel on Intermittent Immersion (1 min. in, 4 min. out) in Aerated Hot Tap Water at Temperature of 140 to 145 deg. F. for 21 Days. Grams, loss in weight after removing rust. Specimen 22-gage—1 in. x 2¼ in.

Alloys added, per cent	Phosphorus Content, Per cent							
	0.02	0.05	0.10	0.20	0.30	0.50	0.75	1.00
None	....	1.61	1.66	1.64	1.45	1.78	1.59	1.56
0.5 Ni	1.65	1.59	1.82	1.56	1.49	1.65	1.66	1.49
0.25 Cu	1.63	1.79	....	....	1.55	1.47	1.60	1.58
1.0 Cu	1.77	....	1.55	....	1.93	1.65	1.42	1.52

There appear to be no significant differences on the basis of weight loss, but the specimens with 0.30 per cent or less P corroded uniformly without pitting, while those of 0.50 per cent or more P showed pitting.

For the alloys studied, corrosion under immersed or intermittently immersed conditions showed neither advantage or disadvantage due to presence of P up to at least 0.3 per cent.

Oxidation and Scaling

A rough test on oxidation and scaling was made by heating ends of broken impact bars at 1400 deg. F. for 4 hrs. in an electric muffle furnace with the door open, and allowing the specimens to cool in the furnace. The brick on which the specimens rested was rotated periodically.

The specimens and their detached scale were photographed, Fig. 15, then the specimens were sand blasted free of scale and weighed. The weight losses are plotted in Fig. 16. Phosphorus tends to decrease scaling under the conditions of the test. Up to 0.30 per cent P, the steels were free-scaling, above that, the scale was quite adherent.

Electrical Resistance

Data on electrical resistance are shown in Fig. 17. The increase in resistance was directly proportional to the amount of phosphorus present, up to about 0.5 per cent. With more phosphorus, the increase in resistance was not as rapid. As shown by the Curves 1, 2, and 3, the addition of 0.5 per cent Ni, 0.3 per cent Cu, and 1.0 per cent Cu, raises the resistance a fixed amount for the whole series of alloys. More copper would most probably cause the resistance to decrease for two reasons: First, with the Fe-Cu alloys, a maximum resistance is reached at about 1.5 per cent Cu; with about 7 per cent Cu, the resistance is again about the same as for ingot iron; second, more copper seems to cause a decrease in the solubility of phosphorus in iron. Curve 4 represents the resistance of a series of Cu-P-Fe alloys in which the amount of copper is equal to 5 times the phosphorus content. After the addition of 0.6 per cent P and 3.2 per cent Cu, the resistance falls. An alloy of 0.88 per cent P and 4.8 per cent Cu has a somewhat lower resistance than the 0.6 per cent plus 3.2 per cent Cu alloy, while it has about the same resistance as an alloy containing 0.46 per cent P, and no other alloying element.

Magnetic Properties

A series of low carbon alloys containing 0.015 to 1.0 per cent phosphorus was used, in the form of 22 gage sheets. Six specimens in the form of rings, 1⅞ in. inside diameter and 2¼ in. outside diameter, were cut from each sheet, then annealed in an airtight container for 1 hr. at 1875 deg. F. followed by slow cooling, the entire annealing cycle requiring about 10 hrs. After the magnetic tests were made, it was decided to again anneal specimens 39, 5, and 13, this time for 4 hrs. at 1830 deg. F. followed by slow cooling to room temperature. The second treatment was carried out in hydrogen. The 1 per cent phosphorus as well as the 0.10 per cent phosphorus sample were considerably improved by the second treatment. Be-

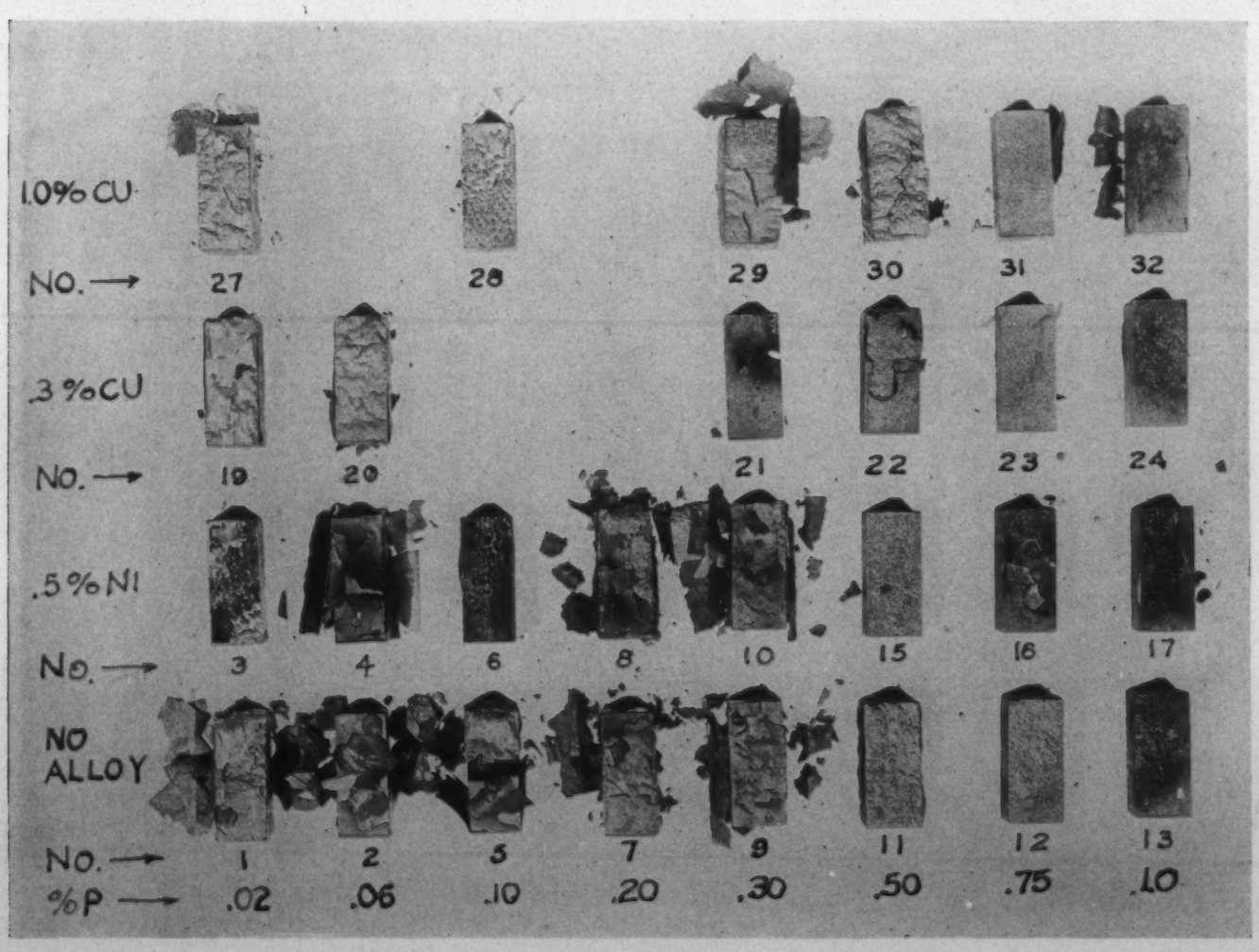


Fig. 15.—Scaling of Samples of Phosphorus Steels at 1400 deg. F.

cause heat treatment has a profound effect on the magnetic properties of iron, it is probable that the properties of the series of alloys studied could be somewhat improved by using the proper heat treatment.

Results of the magnetic tests are set forth in Table 14. It is evident that, for this particular group of samples, the permeability increases with an increase in phosphorus content. The permeability of sample 39 (remelted ingot iron) is low compared to values usually given for a good grade of ingot iron properly heat treated. The maximum permeability of ingot iron has been reported to be as high as 20,000; the usual value, however, is about 9,500.

Table 14. Magnetic data from tests of phosphorus iron.

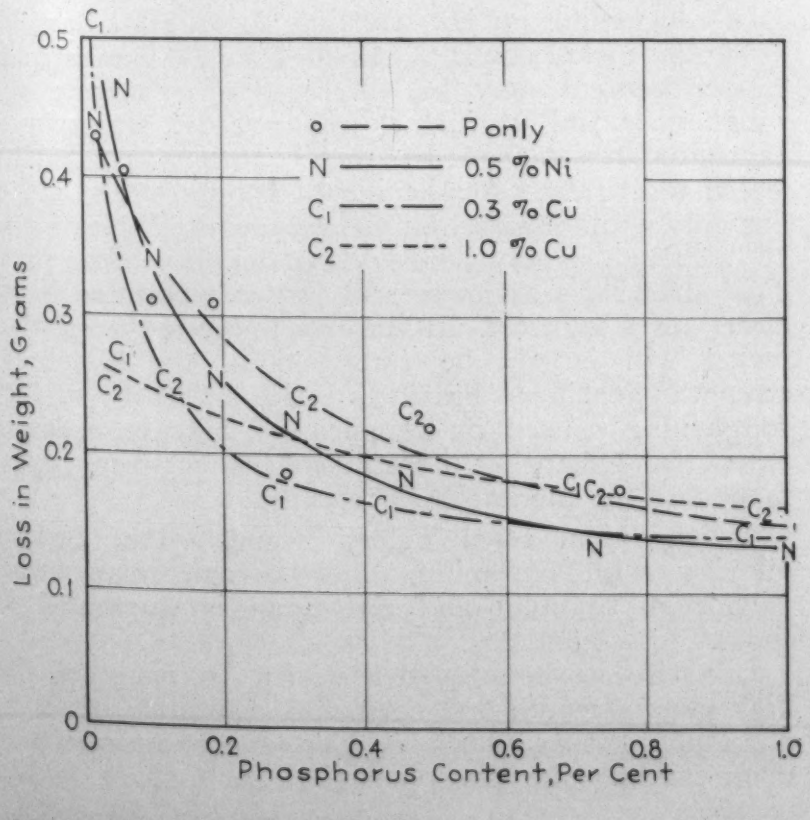
Sample	Phosphorus, per cent	Hc [a] Oersteds/cm.	Br [b] Kilogausses	max. [c]	$B_H=10$ [d] Kilogausses	Hysteresis loss, Erg./cm.³/cycle [e]
39	0.015	1.31	7.9	3180	13.7	3850
2	0.06	1.40	8.5	2960	12.7	4470
5	0.10	1.80	8.8	2660	13.5	5460
7	0.19	1.32	9.0	3250	13.2	4230
9	0.29	1.10	8.9	4050	12.9	3400
11	0.49	0.95	9.6	5350	12.4	3040
12	0.76	0.80	9.0	6460	14.5	2510
13	1.07	0.80	9.0	5860	14.2	2470
Result of second heat treatment						
39	0.015	1.10	8.8	3530	10.4	3976
5	0.10	1.00	8.9	5420	14.1	3073
13	1.07	0.58	9.0	8190	14.6	1787

[a] Hc = Coercive force expressed in oersteds/cm. It is the reversed magnetizing force that is just sufficient to reduce the residual induction to zero.
[b] Br = Residual induction expressed in Kilogausses. It is the magnetic induction that remains in a material when the effective magnetizing force has been reduced to zero.
[c] max. is the maximum permeability.
[d] $B_H=10$ is the magnetic induction obtained with a magnetic force of 10 oersteds/cm.
[e] Hysteresis loss for magnetic induction (B) of 10 kilogausses.

In a producer's handbook there is given a maximum permeability of 8200 for extra special power transformer sheet. The permeability value for Sample 13 containing 1 per cent phosphorus was found to be approximately 8190.

The hysteresis losses per cycle are obtained by measuring the area enclosed in the hysteresis loops and computing the loss for B = 10 kilogauss. The relation of hysteresis loss to phosphorus content is recorded graphically in Fig. 18. Values obtained after

Fig. 16.—Weight Loss at 1400 deg. F. of Phosphorus Steels.



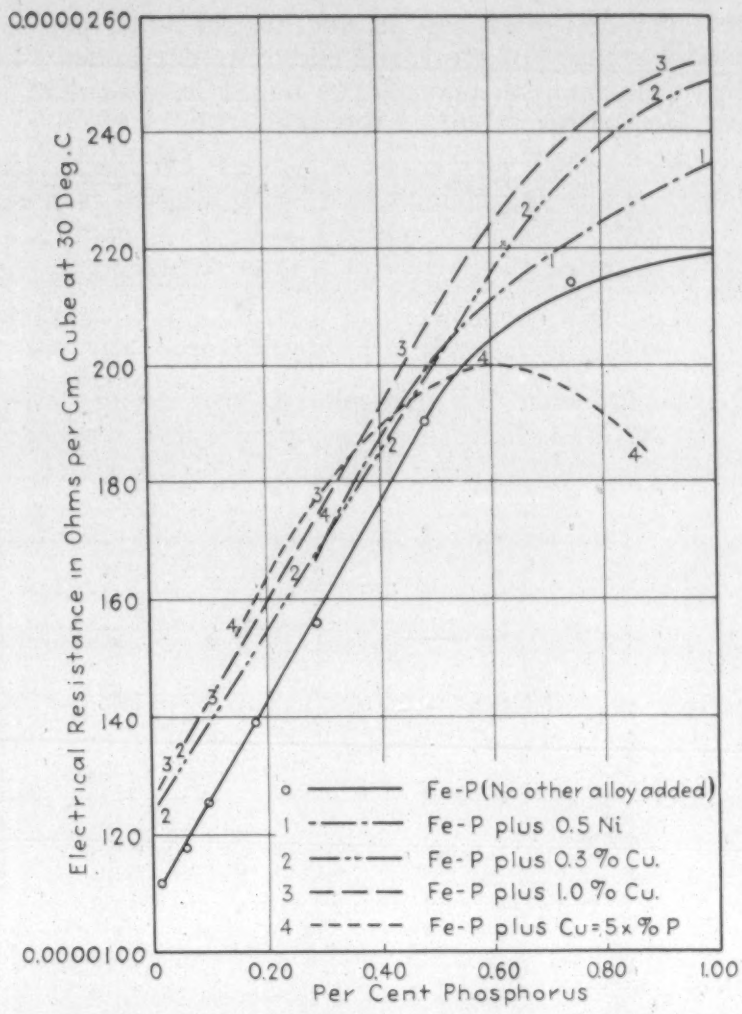

Electrical Resistance in Ohms per Cm Cube at 30 Deg. C
Per Cent Phosphorus
Fe-P (No other alloy added)
Fe-P plus 0.5 Ni
Fe-P plus 0.3 % Cu.
Fe-P plus 1.0 % Cu.
Fe-P plus Cu = 5 x % P

Fig. 17.—Electrical Resistance at 86 deg. F. of Low Carbon, Box Annealed 22 Gage Sheets.

the second heat treatment have been recorded as single points underneath the curve.

According to Greiner, Marsh, and Stoughton,[5] the hysteresis loss of 4 per cent silicon steel transformer sheet varies from 600 to 1200 ergs/cu.cm./cycle, depending upon the quality of the material and its heat treatment. The effect of carbon content on hysteresis loss is very large, a carbon content of 0.01 per cent causing an increase in the hysteresis loss of 800 ergs/cu.cm./cycle. The samples of phosphorus-bearing sheet contained from 0.01 to 0.02 per cent carbon.

By careful melting, rolling, and heat treatment it may be possible to produce a 1 per cent phosphorous iron sheet with the same hysteresis loss as a 4 per cent silicon sheet steel. Yensen[6] states, "phosphorus up to 0.015 per cent increases the hysteresis loss by 200 ergs/cu.cm./cycle, further increase of phosphorus has no effect." However, his data end at 0.1 per cent phosphorus. Fig. 18 indicated a maximum hysteresis loss at 0.1 per cent phosphorus with a further increase in phosphorus causing a decrease in the hysteresis loss.

Hysteresis losses are only a few of the losses encountered in a transformer core. For a 4 per cent silicon steel sheet, the eddy current losses represent about 32 per cent of the total. With all other variables maintained constant, the eddy current loss is inversely proportional to the resistivity of the material. The resistivity of a 1 per cent phosphorous alloy is about 22 microhms per cu.cm., while the resistivity of a 4 per cent silicon steel is approximately 65 microhms per cu.cm.; therefore the eddy current losses would be approximately 3 times greater for the 1 per cent phosphorous alloy. Provided that the hysteresis loss of a 1 per cent phosphorous material were the same as that of a 4 per cent silicon steel, the total losses for

the 1 per cent phosphorous steel would be 60 per cent greater because of increased eddy current losses. The use of silicon with phosphorus might be useful in increasing the resistivity of the alloy.

Other special properties of steels carrying phosphorus as alloying element are being studied, some of which are of decided interest and it is planned to report on those properties in a later article.

Summary

THE influence of phosphorus in raising yield strength has been shown to operate in the presence of several other alloying elements.

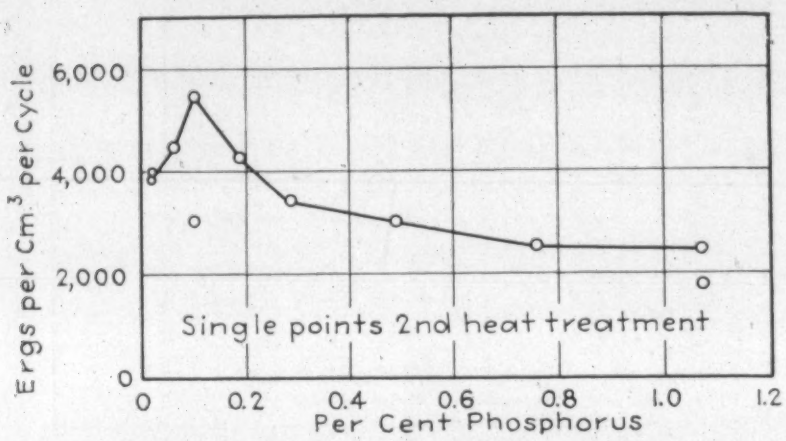


Fig. 18.—Hysteresis Loss of Phosphorus Steels.

The drop in notched bar impact at 0.27 per cent P noted by d'Amico and discussed in a previous publication[1] can be shifted to somewhat higher phosphorus contents and the level of impact resistance raised by a grain-refining addition of aluminum. While this drop is moved toward lower phosphorus contents by increase in carbon, carbon up to 0.20 of 0.25 per cent is not incompatible with fair impact toughness in steels of about 0.25 per cent phosphorus. By suitable heat treatment, usually an anneal below Ar_3. impact brittleness of a steel of border-line composition may often be prevented.

A high degree of static toughness and formability is retained at phosphorus contents well above that at which impact brittleness occurs.

Most alloying elements used in high-yield strength low alloy steels are. in the amounts likely to be used in such steels, compatible with around 0.25 to 0.30 per cent phosphorus without inducing serious impact brittleness. About the only exceptions are silicon and carbon, which in relatively large amounts appear to favor brittleness. The addition of chromium definitely, and of nickel, copper or molybdenum somewhat less definitely, tends toward impact toughness of phosphorous steels. In steels already grain-refined by aluminum, the effect of titanium or zirconium may still be helpful but the influence is not as marked as that of chromium.

There are indications that the use of several other alloying elements in a complex steel may accentuate the toughening effect, though of course there is a limit to the total hardening that may be resorted to before the toughness will again deteriorate.

Resistance to atmospheric corrosion is improved by increase in phosphorus above the usual limits. This is true for plain P and Ni-P steels as well as for Cu-P.

The experimental evidence has strengthened the belief based on data previously available in the literature,[1] that phosphorus deserves consideration as an alloying element in the development of steels of high yield strength and corrosion resistance.

From these and other studies, the course of development of the high-yield strength, phosphorus-bearing steels with their improved atmospheric corrosion resistance appears quite clear. The evidence contained in Tables 1 and 11 is sufficient to warrant the view that, in the cheaper steels, phosphorus alone might be employed. While the loss in impact-ductility at around 0.3 per cent P may not necessarily impose a limitation on the use of high phosphorus in sheet (since the static ductility and the bend tests on sheet containing much more phosphorus are still good) it may be desirable to use the steel in sections thicker than sheet where, for need of impact-ductility, some limitation on phosphorus content must be imposed. In that case one may employ with the phosphorus one or more alloying elements to augment the yield and tensile strengths and the corrosion resistance, and yet retain such impact-ductility in the steel as not to restrict its use.

With the exception of carbon and silicon the usual alloying elements within certain percentages at least, appear to be either neutral or beneficial to the impact of "border-line" phosphorous steels. This would necessitate limiting the steels of higher phosphorus to those of medium or low carbon and those of not too high silicon contents unless these elements are supplemented by others, like chromium, which tend to offset brittleness. Hence one would anticipate that the development of complex phosphorous steels will follow along the lines of adding the element or elements which entail the least expense and the greatest effect from the standpoint of alloy cost and properties.

According to Tables 5, 10 and 11, of the common, inexpensive alloying elements, copper is one of the most effective in raising the yield strength of phosphorous steels. Since copper with phosphorus is excellent from the standpoint of atmospheric corrosion resistance as well, Table 12, steels in which this combination of elements is to be found are likely to be in general use. They may be limited by loss of room temperature-ductility to from 0.25 to 0.30 per cent P, but their copper contents may well be 1 or more per cent.

As copper containing steels are susceptible to surface roughening on hot working above 2000 deg. F., minimum nickel contents of one-third to one-half the copper content may be employed[7] to mitigate the roughening and to further enhance the atmospheric corrosion resistance. In the quantities needed to lessen the surface roughening of copper steels, nickel has only a minor effect on yield strength, Tables 1 and 10, although it may improve the ductility. The principal drawback to its use in larger quantities is its effect on alloy cost. It may be expected then that nickel will largely be employed in the high-yield strength phosphorus bearing steels to offset the surface roughening caused by copper and only to a lesser extent for enhancing the atmospheric corrosion resistance and the mechanical properties.

It is evident from Tables 5 and 9 that further alloying with chromium, molybdenum, manganese, vanadium, titanium and zirconium is warranted at times.

Likewise it should prove useful, in many of the high yield strength and corrosion resistance steels, to make phosphorus additions. Conversely, an insistence upon holding the phosphorus in such steels to the

normal phosphorus limit of say 0.05 per cent seems illogical when five or six times that amount appears in steels of the properties recorded above. The old classification of phosphorus as a "nuisance element" cannot be accepted today without definite proof that in the particular type of steel and for the particular use intended, it really is a nuisance. In some types of steel and for some uses it may rather be a boon.

After the above was written an article by K. Daeves, "Die Weiterentwinklung witterbeständiger Stähle." *Archiv. f. d. Eisenhüttenwesen,* vol. 9, July, 1935, pages 37 to 40, appeared in which exposure tests are cited to justify the conclusions that steel with 0.3 per cent Cu and 0.06 to 0.20 per cent P is more weather-resistant than that with either 0.3 or 1 per cent Cu and under 0.04 per cent P; that the same thing holds when the steel is galvanized; and that a Cu-P steel painted after slight weathering to remove mill scale, holds the paint coat extraordinarily well.

Two year exposure tests on fence wire showed that the reduction in tensile strength due to rusting was only ¾ as much with plain copper steels and only ½ as much with phosphorized copper steels as with one in which both phosphorus and copper have been kept as low as is commercially feasible.

Daeves comments that at the same time we are bewailing the low atmospheric corrosion resistance of ordinary steel, we are imposing specifications to limit the phosphorus content. He says "One should step back a bit and determine for what purposes a higher phosphorus content would be injurious rather than to set up "purity" as a measure of the utility of a steel without further consideration. Through such baseless, generalized specifications, technical development is greatly hampered."

References (Concluded)

5. Greiner, E. S., J. S. Marsh and B. Stoughton. "The Alloys of Iron and Silicon." McGraw-Hill Book Co., 1933.
6. Yensen, T. D. "Magnetic Materials in the Year 1931." Year book, American Iron and Steel Institute, Vol. 21, 1931, p. 452 to 482.
7. Lorig, C. H. Discussion of paper by C. S. Smith and E. W. Palmer: "The Precipitation-Hardening of Copper Steels." *Transactions,* American Institute of Mining and Metallurgical Engineers, Iron and Steel Division, Vol. 105, 1933, pages 165-167.

Creep Data on Still Tube Steels

THE BABCOCK AND WILCOX TUBE CO., Beaver Falls, Pa., has issued a 1935 revision of Technical Bulletin No. 6a, "Digest of Properties, Carbon and Alloy Steels for Cracking-Still Tubes."

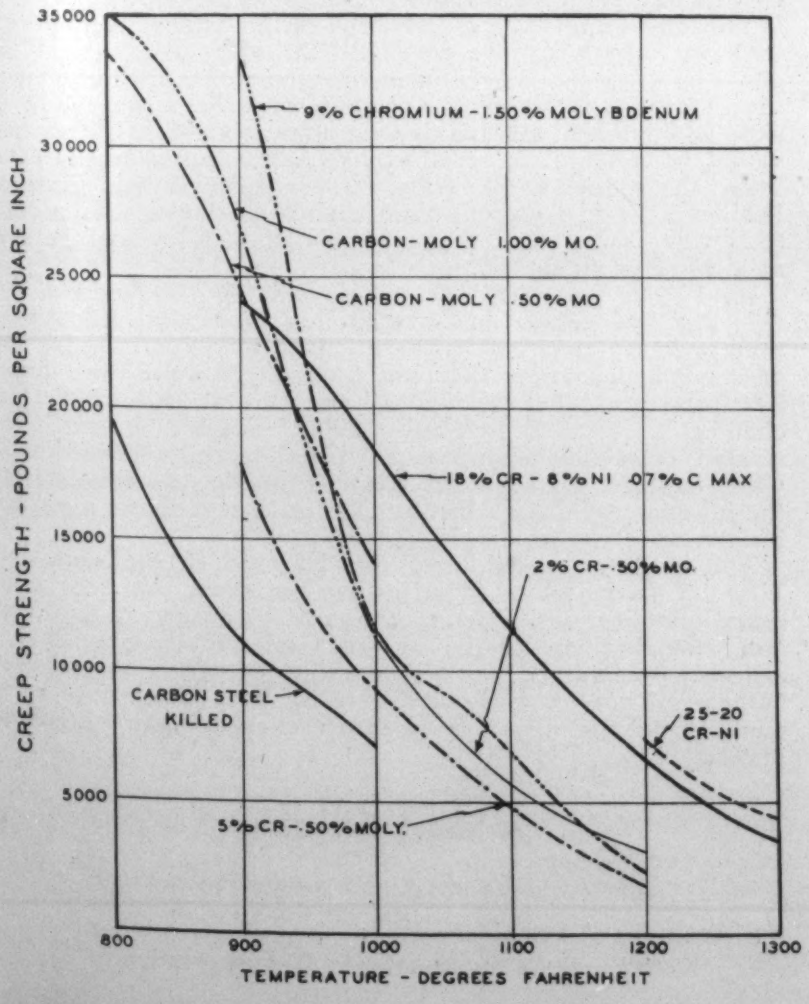
This gives short-time tensile and long-time creep properties, at elevated temperatures, of 0.10 to 0.20 per cent C steel, open and killed (the latter has much the better creep properties); of 0.50 and 1 per cent Mo steels; of 2 and 5 per cent Cr steels with 0.50 per cent Mo; of 9 Cr, 1.50 per cent Mo; of 18 Cr, 8 Ni, and 25 Cr, 20 per cent Ni.

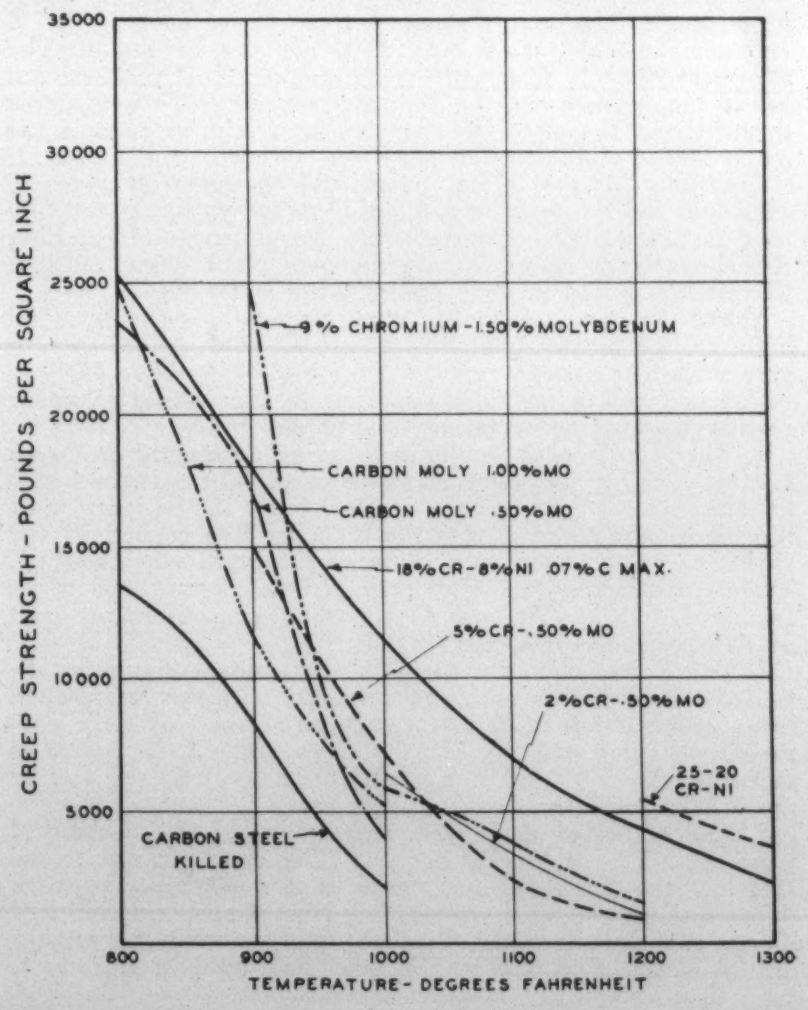
The creep data, as determined by Norton at M.I.T. are collected in two figures, reproduced herewith. Reliable creep data on the plain molybdenum steels in particular, have been scarce.

The structure of the different steels are shown in the bulletin, and their corrosion resistance discussed.

Steam plant engineers, as well as users of still tubes, will find these data of interest.

Curves Showing Comparative Creep Strength of B. & W. Alloy Steels — Rate = 1 Per Cent in 100,000 Hrs.





A Long Chuckle!

Possibly A Belly Laugh!

Gathmann, Duco, Electromet, Alcoa, Packer, Ford, et al—Take Notice!

To the Editor: I am enclosing a copy of a description of a very secret process concerning which I was consulted a short time ago. I believe that it will represent another addition to your collection of absurdities.

The gentleman who called on me a short time ago was considering the investment of a considerable sum of money in the exploitation of this process. The so-called inventor refused to divulge the process until the money was advanced. Obviously, the prospective inventor did not invest after I got through discussing the matter with him.

Sincerely yours,
V. O. HOMERBURG.

M. I. T.
Cambridge, Mass.

The X Metal Treatment

The formula used in the X treatment of metals was originated several years ago by a resident of Boston who experimented with it in a small way with successful results.

In 1931 the formula was disclosed to E. J. T. of Milton in an agreement with the owners whereby E. J. T. was to further test the value of the X treatment after ascertaining from reliable sources that there were no treatments on the market or known to any metallurgists that would produce results that the X treatment showed.

As the X treatment also does not show up in analysis, no fear was felt that it would be acquired by any theft of samples of the treated metals, so after considerable experimenting and investigation covering about a period of 18 months, Mr. T. found under actual working conditions that the X treatment was of incalculable value to the metal industry. Also while numerous other treatments had been tried, none seemed to have the scope covered by the X treatment.

No radical change is necessary for the metal industry to adopt the X treatment as the process is very simple in its application, requiring only the addition of the X materials to the molten mass of metals just before the metal is to be poured into the ingot or other molds.

The amount of material used in the X treatment is about 60 ounces to the ton of metal and the entire cost of the X treatment would not be over $2.00 per ton of metal. The adoption of the X treatment by the metal industry would not affect the market for the X materials, as there are ample quantities of the materials that can be produced even if the metal industry increased to ten times its normal business.

Contracts for the X materials could be made on a yearly or longer basis subject to a monthly delivery, and practically no elaborate equipment is necessary for storing and handling the X materials, a small space in each plant being all that would be required to store and mix the materials.

While the X treatment has many applications to the metal industry, the following high spots are all that is necessary to give some idea of its value and these high spots have all been tested and *not in the laboratory* but in the *foundries* under regular working or operating conditions:

1. The X treatment results in a saving of several dollars a ton by reducing the ingot losses to zero. These ingot losses are the result of gas pockets or blow holes in the interior of the ingots and there is also the cropping loss caused by the shrinking of the metal at the top of the ingot when cooling. Twenty-two million tons of this class of steel went through the furnaces in 1931. (At least $5 per ton saving on 50 per cent of the tonnage is conservative).

2. The X treatment increases the corrosion resisting qualities of the higher carbon steels on a par with the low carbon irons which sell for $20 a ton more on account of their corrosion resisting qualities. As the cost of the X treatment is about $2 per ton, there is a saving of at least $8 per ton by the X treatment.

3. The X treated steels show a reduction in the mechanical working cost of at least $2 per ton. This saving is due to the fact that the X treated steel requires less annealing between the rolling process, as a sample of X treated steel was reduced 70 per cent in one cold rolling without harming the quality of the metal. (An 0.26 carbon steel was used in this test).

4. The steel used in the oil refineries constitute a loss of over $100,000,000 per year due to the corrosion. The metal used is a high chrome and nickel content (18 and 8). This loss could be reduced a tleast one half by the use of X treated chrome steel, eliminating the nickel, as the X treatment takes the place of nickel. The nickel is the metal that is acted upon by the sulphuric acid produced by the high temperature employed in the cracking process of crude oils.

5. The production of die steels containing 2 per cent carbon and 12 per cent chromium (now selling at $1500 to $2500 per ton) at present has a monopoly of the heavy die market, whereas a superior product can be produced with the X treatment of a steel having only a 1.25 per cent carbon and a 9 per cent chromium content at a base cost of $46 per ton plus a melting and molding charge. This X treated steel could be sold at a good profit at $600 per ton and would also have other savings by reducing machining costs at least 25 per cent.

6. Aluminum of a higher tensile strength can be made by the X treatment, by the addition of a small percentage of copper, 1 per cent. (See copy of the U. S. Arsenal Report 00 and 1 dot untreated).

7. Aluminum that can be drawn into rods or bars that can be easily machined in automatic machines can be made with the X treatment and this type of metal would bring a much higher price per pound, and a product of this quality is badly needed by the trade as the present metal on the market is very unsatisfactory.

8. As the X treatment reduces sulphur and carbon, the treatment becomes very valuable for the trade in the drawn steel rod business for, while not only increased strength of material is produced, the treated steel becomes as easily machinable as the higher sulphur content steels. This particular feature of the steel industry is confined to the automatic machines, making screws, nuts, and small bolts where strength is necessary.

U. S. arsenal report	-1 Dot duraluminum
00-6-7 virgin aluminum	-2 Dot aluminum 99% copper 1% treated
00-Untreated aluminum	
-6 Treated aluminum	-3 Dot aluminum 99% copper 1% treated
-7 Treated aluminum	

9. The application of the X treatment to steels for automobile bodies will eliminate the expense of Parkerizing that is now employed to give the corrosion resisting qualities that are necessary to the auto body business.

The making of cylinder castings that can be hardened so that they can not be affected or worn by carbon and the molding of crankshafts without the use of hydraulic pressure would give the parties controlling the X treatment practically a monopoly in this line as the production costs would be much less than with the hydraulic method. This crankshaft business would require, in addition to the X treatment a low carbon, low chromium content, 5 per cent chromium about 0.05 to 0.20 per cent carbon.

The casting of valves where a bright finish is required, such as faucets, can be accomplished without any great expense by using the X treatment in combination with chromium thus requiring no plating expenses, and the manufacture of sink and kitchen utensils having a mirror silver finish that would be resistant to scratching or discoloration would eliminate the monel metal from 90 per cent of this class of business. At the present time a sink of monel sells around $225 whereas a sink of the X treated metal would be sold at a good profit at $30.

10. The X treatment as applied to brass composed of 1/3 zinc and 2/3 copper has produced a brass that is stronger than ordinary steel and, while no elaborate experimenting has been conducted along this line, the samples have been drawn into tubing and put through all the hardest part of the mechanical working without any trouble being encountered. The treated brass also shows marked resistance to discoloration when exposed to the moist weather and has possibilities for the jewelry trade as a substitute for gold as it shows a marked resistance to the gold acid tests.

The chrome treated steel can be used in the same line (jewelry business) as a substitute for silver with the additional qualifications of being hardened by heating to 1750 deg. and when hardened can be given a mirror silver finish that can only be scratched by carborundum or emery and the diamond, and does not discolor or tarnish as silver does when exposed to the air, and is much cheaper than chromium plating.

A Short Chuckle

Rôle on, thou deep and dark blue ocean!

Sign at the A.I.M.E. meeting:
"The Roll of Metals in Transportation."

LETTERS TO THE EDITOR

Poetry for Metallurgists

To the Editor: Your publication is much too dry. It needs a little lubrication. Why not have a column entitled "Poetry for Metallurgists"?

The first thing to print in that column would be "Science Simplified for Steel Works Stenographers" by Captain Gerard Firth of the Firth Sterling Steel Co.

My own aspirations are to write an "Outline of Metallography" in verse. The following jottings will give you an idea of what might be done:

Preceding metallography
I studied, first, petrography
Which deals with structures found in rocks
and slags.
I then applied this knowledge
To some ores I found in college
Which the miners used to stow away in bags.

But the structures of the metals,
Be they melted down in kettles
Or rolled to sheet or drawn out into wire,
Soon took my whole attention
And I found that under tension
The grains were elongated but entire.

I found in the beginning
That annealing produced twinning
With a corresponding drop in tensile strength;
While on reapplying strain
Hardness returns again,
In proportion to the increase in the length.

Then we took up the alloys
Which the engineer employs
And found they had dendritic segregation,
Which will often disappear
On annealing, for it's clear
They're, after all, a crystal aggregation.

We soon learned that martensite
Is minutely-grained ferrite
With sub-microscopic cementite in suspension.
But it took us many years
To find that this occurs
In alloys far too numerous to mention.

Of course I could run on in this way and cover the whole of metallography from "Alclad to Zamac" but the only thing you editors will give space to, ungrudgingly, is ADVERTISEMENTS.

WILLIAM CAMPBELL

Columbia University,
New York

The Editors' Reply

We'll not begrudge our space to those
Who rhyme as well as Campbell.
In fact, of yore we've published verse
By Peters and deForest.

But let us warn, don't do it worse.
(We draw the line at Gertrude Stein.)
We'll print or else *we* will decline,
Just as the spirit moves us.

No "outside reader" 'll dare to say
That "this won't do for M. & A."
And as for prose or poem Ads.,
We'd like to print just Scads and Scads!

Art and Poetry for the Technician

To the Editor: It is with a keen sense of interest that the writer has noted the excellent drawings by Charles Perry Weimer in the recent issues of METALS AND ALLOYS, particularly the one in the January issue, titled "1936 MARCHES ON!" The incorporation of such material in a technical journal is not only a delight to the artistically minded scientist, but a source of inspiration to the engineering fraternity in general.

The writer has recently completed a painstaking three-year research project, studded with many unavoidable anxieties and temporary failures. In such moments, it has been the experience that an *altruistic philosophy* and a recognition of the beauty of *creating* rarely fails to raise one from the "depths." Too often our noses are so close to the grindwheel of specialized activity that our eyes fail to see a pattern *in toto*. Such contributions as those of Mr. Weimer give us this all-embracing vision.

The writer suggests a further innovation. In conjunction with the brush of the artist a desired effect may be further enlarged by employing the pen of the poet. Word pictures are sometimes powerful stimulants. As an example, the writer humbly submits the following picture of a recent explosion in his laboratory which, though perhaps somewhat depressing in its theme, will serve as an example:

EXPLOSION—August, 1935

In my laboratory, reeling shapes of white fumes have
dashed out their brains
On the glass and metal cadavers of my once-mighty
brain children.
Their skeletons lie sprawling, undisturbed, on the web
of glass tubes and metal wires,
Mating promiscuously with the dark dust of dead
flames.

Outside the sky is molten cobalt glass and the air is a
boiling syrup.
The once-emerald ivy traces its bridal symbols on the
dull brick,
Dumbly insatiate with the passionate embrace of crumbling walls,
Drooping, wearily, under the fierce thrust of dead
flames.

O cruel fate that has spared the father to bury his
murdered children.
Here, alone, wallowing in the debris of my wrecked
temple,
Strangely inarticulate I stand, gazing upon my scant
thimbleful of memories,
Dreaming, fitfully, of the charred lust of dead flames.

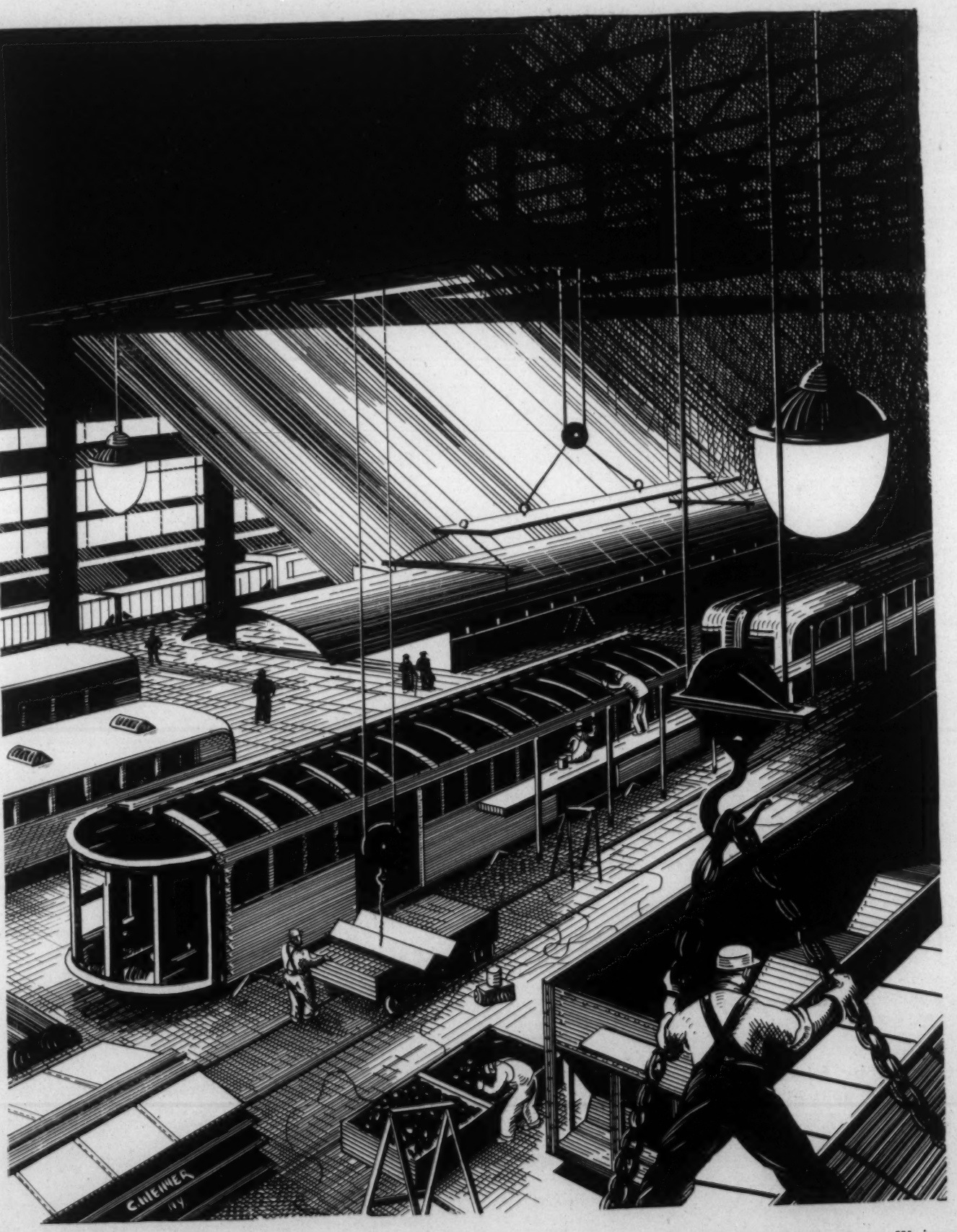
The writer is anxious to know what reaction his suggestion may draw from his colleagues.

MIKE A. MILLER.

Department of Chemistry
University of Michigan
Ann Arbor, Mich.

(Note: The above is an original unpublished poem by the writer.)

Charles Perry Weimer of New York, the artist referred to in this letter to the editor, has been preparing striking black and white one-page illustrations for METALS & ALLOYS since July, 1935, inclusive, with the exception of one month, October. They have attracted wide attention and we believe they have added to the appearance of the magazine. His drawings are described as modernistic, yet conservative in execution. After being graduated from the Elkins, W. Va., high school, he studied chemical engineering at the University of Pittsburgh, but dropped the test tube and retort to take up the study of art at Carnegie Tech and the Art Institute of Pittsburgh. His broad experience and knowledge show in the breadth of his interpretation when rendering a wide range of subjects in his individual, dramatic style.—Editor.



Drawing by Charles Perry Weimer

CAR CONSTRUCTION

Low Alloy, High Yield-Strength Structural Steels

An Extended Abstract

In the Construction of This Bridge at San Francisco, Nickel Steels Were Used to Give Adequate Strength to Highly Stressed Members. In the as-rolled condition the steel had a yield strength of 55,000 p.s.i. (Courtesy of International Nickel Co.)

AT THE recent conventions of two large technical societies, the following papers were presented on the general subject of the "low alloy, high tensile" steels. They were as follows:

"Trends in the Metallurgy of Low Alloy, High Strength Structural Steels" by H. W. Gillett, chief technical advisor, Battelle Memorial Institute, Columbus, Ohio, and editorial director, METALS & ALLOYS.

"Choosing a Composition for Low Alloy, High Strength Steel" by S. Epstein, J. H. Nead and J. W. Halley. Mr. Epstein is metallurgist, Battelle Memorial Institute and Messrs. Nead and Halley, metallurgists, Inland Steel Co., Chicago.

"Carbon and Low Alloy Steels" by Edwin F. Cone, editor, METALS & ALLOYS, New York.

The paper by H. W. Gillett was one of a symposium on "Metals in New Transportation" at the February meeting of the American Institute of Mining and Metallurgical Engineers in New York. The one by E. F. Cone was delivered at a symposium on "High-Strength Constructional Metals" at the Regional Meeting of the American Society for Testing Materials at Pittsburgh, March 4. The Epstein paper was presented at a session on General Metallurgy at the mining engineers' February meeting.

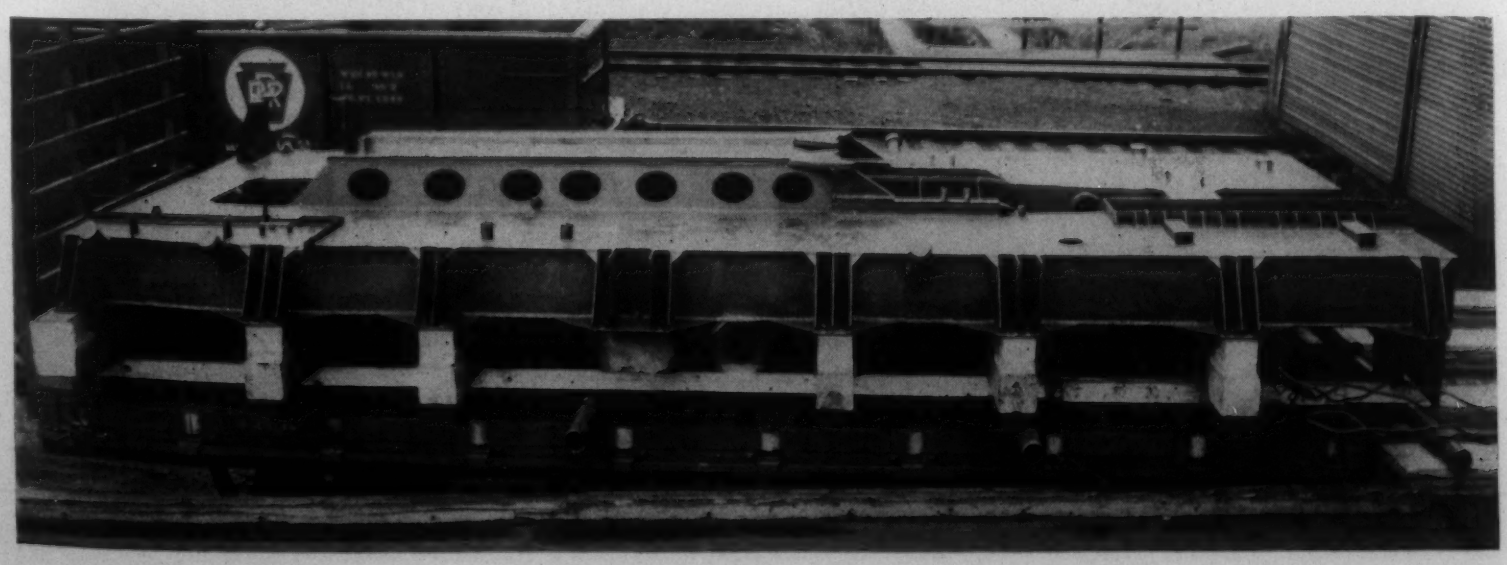
A general review of these discussions, prepared by the editors of METALS & ALLOYS, is presented in this article.

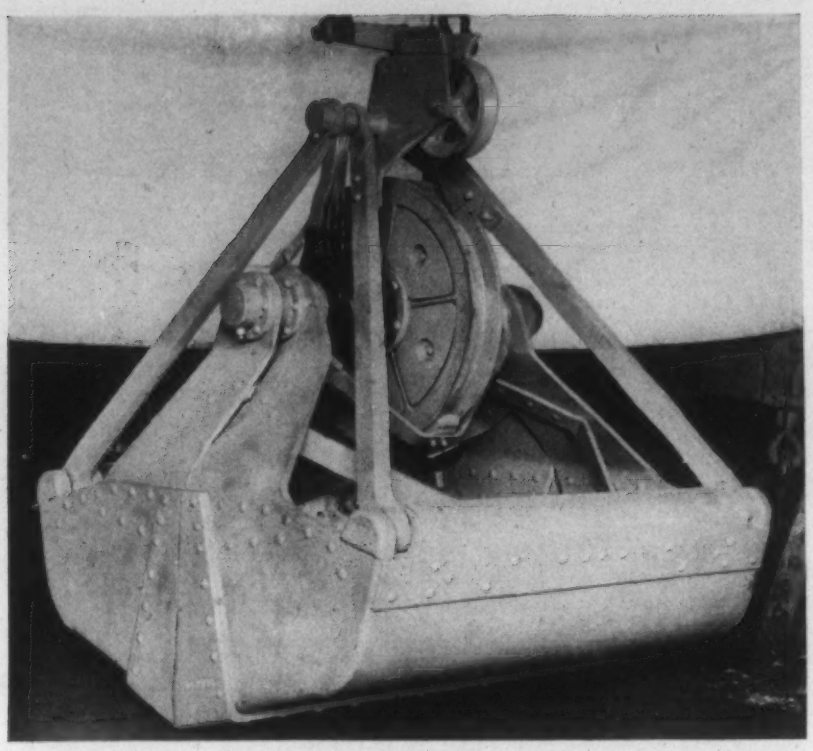
CURRENT INTEREST RUNS HIGH in the cheap alloy structural steels of 50,000 to 60,000 lbs. per sq. in. yield strength, among the engineers who use them and the metallurgists who produce them. The engineers have dealt with them from the point of view of what they can do with stronger material than the usual 30,000 lbs. per sq. in. yield strength structural steel. At the meeting of the American Welding Society last fall Gibson [1] showed slides of many heavy welded moving parts of cranes and the like in which such steels were utilized, and pointed out that their design was based on the yield strength of the available steel.

Importance of Yield-Strength

Yield-strength design has long been important in bridges and steamships, but it required the present plight of the railroads to bring out the value of ceas-

One of the Bed Plates of the "Comet," the High-Speed, Stream-Lined Train of the N. Y., N. H. & H. R. R. It is made of "Cromansil" steel produced by the Lukens Steel Co., and is 19 ft. long and 11 in. deep. (Courtesy of Lukens Steel Co.)





This Bucket, Built by the Hayward Co., New York, N. Y., is Constructed of "Cromansil" Steel, produced by Lukens Steel Co. It was possible to design it with 5 per cent less total weight than one of ordinary carbon steel, and with an increase of 40 per cent in strength. (Courtesy of Lukens Steel Co.)

ing to lug dead weight around in freight cars and to bring about a redesign of the car to lighten it by using materials of higher yield strength.

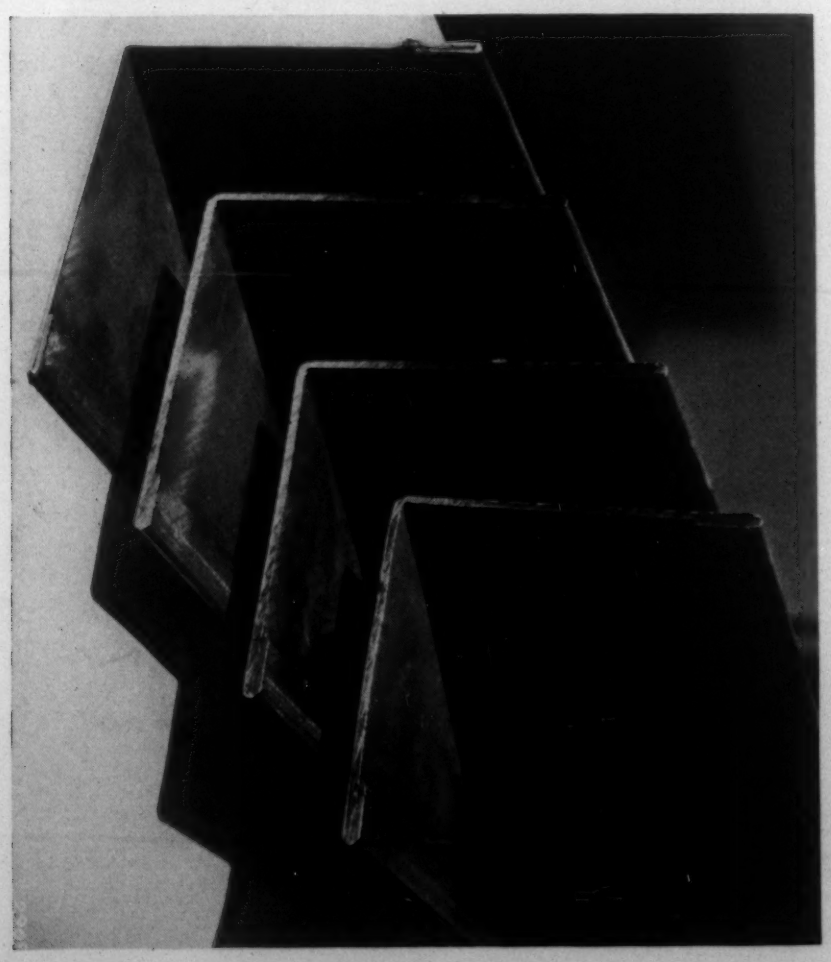
The high speed passenger trains and aircraft that are in motion a large proportion of the time can amortize the cost of the aristocratic alloys—18 and 8 and the aluminum alloys—but the lower speed freight cars which stay on a siding so much cannot, so the transportation problem calling for the largest tonnage of low alloy steels is confined to the cheap ones.

The Civil Engineers will have their innings at a symposium in Pittsburgh in the fall, at which design problems connected with materials of high yield-strength will be discussed. The fact that the type of failure primarily to be guarded against under static stress is the "crumpling" type, where the effective strength of the structure is the yield strength of the material in the structure, has, of course, been referred to in all discussions of the subject.

In any such situation it is always a sort of chicken and egg question whether the metallurgist made the high yield alloys because the engineer wanted them or whether the engineer started to use them because the metallurgist finally made them cheap enough. Whichever was the progenitor, there are a lot of eggs just now. Not less than a score of different low alloy steels, all showing 50,000 lbs. per sq. in yield strength or better and varying but slightly in the other mechanical properties ordinarily determined, are being

A 150-Gallon Drum, made of 14-Gage Armco H-T-50, was Filled with Water and Dropped 23 ft. The weld remained unbroken. (Courtesy of American Rolling Mill Co.)

This Illustrates How Well Armco H-T-50 May be Formed on a Press Brake. (Courtesy of American Rolling Mill Co.)



commercially produced by steel mills of this and other countries, and more than a dozen different ones are made in the United States.

From the paper by Cone, steel companies which have developed low alloy, high yield-strength steels, with the name of the steel, are as follows:

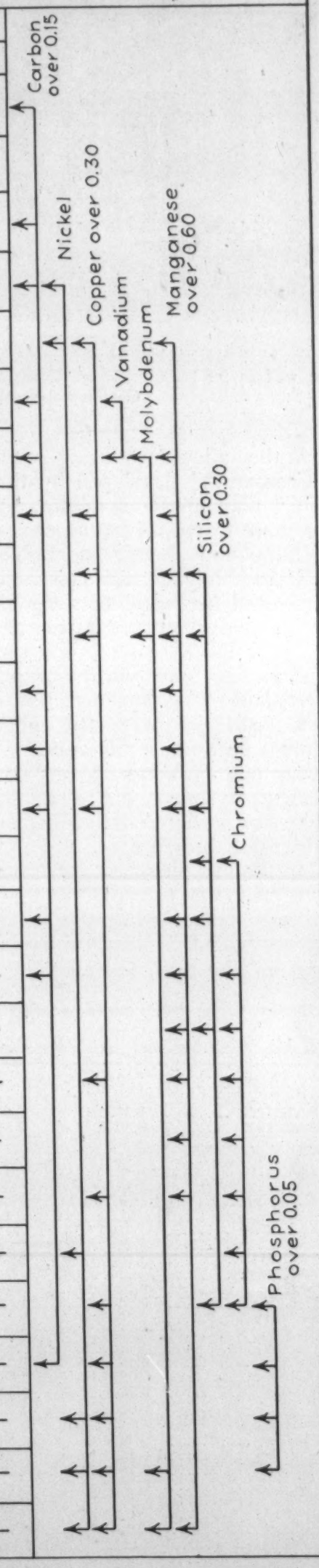
United States Steel Corp., New York.
"Cor-Ten," "Man-Ten," and "Sil-Ten."
Republic Steel Corp., Cleveland.
"RDS Grade 1," "RDS Grade 1A."
Alan Wood Steel Co., Conshohocken, Pa.
"AW 70-90 A," "AW 70-90 B."
Central Iron & Steel Co., Harrisburg, Pa.
"Centralloy Medium," "Centralloy High."
Youngstown Sheet & Tube Co., Youngstown, Ohio.
"Yoloy."
Granite City Steel Co., Granite City, Ill.
"Granite City HS Grade 1," "Granite City HS Grade 2."
Jones & Laughlin Steel Corp., Pittsburgh.
"Jal-Ten."
Continental Steel Corp., Kokomo, Ind.
"Konik."
Inland Steel Co., Chicago.
"Inland Hi-Steel."
American Rolling Mill Co., Middletown, Ohio.
"Armco HT-50."

This arrangement is approximately the order in which the various types appeared on the market.

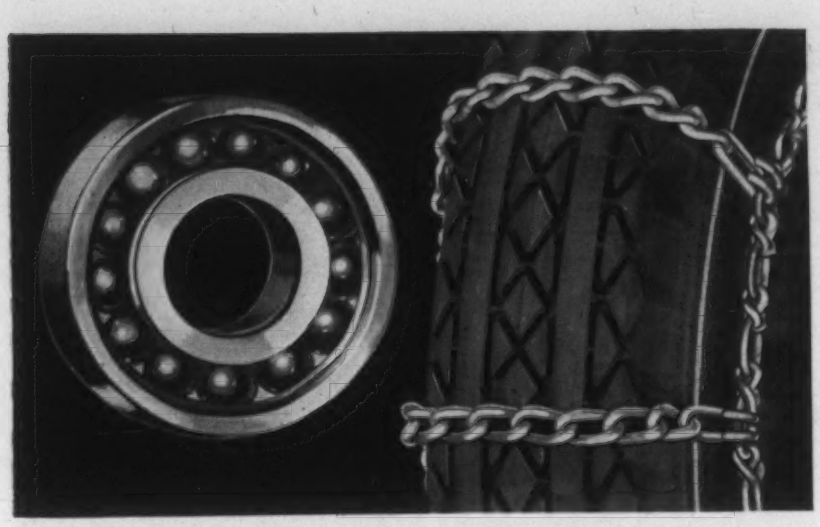
Besides these, there are the earlier steels, such as the well-known nickel and S.A.E. steels, and the standard medium manganese and silicon structural steels. Of more recent date are those types sponsored

TABLE OF COMMERCIAL STRUCTURAL STEELS (Based on Dr. Gillett's Paper)

	PER CENT								
	C	Si	Mn	P	Cu	Cr	Ni	Mo	V
Common Structural	0.20	–	0.50	–	0.20	–	–	–	–
HIGH YIELD STRENGTH STEELS*									
High Carbon	0.45	–	0.50	–	0.20	–	–	–	–
2½ per cent Nickel	0.20	0.20	0.60	–	–	–	2.50	–	–
Yoloy (Youngstown)	0.10	0.25	0.70	–	1.00	–	2.00	–	–
Man Van (U.S. Navy about 1933)	0.18	0.25	1.45	–	0.20	–	–	–	0.18
Manten (U.S. Steel Corp.)	0.23	0.23	1.40	–	0.28	–	–	**	**
Jalten (Jones & Laughlin)	0.25	0.30	1.50	–	0.45	–	–	–	–
Krupp (German)	0.15	0.40	1.40	–	0.45	–	–	–	–
Gutehöffnungshütte (German)	0.15	0.45	1.15	–	0.35	–	–	0.20	–
Delaware River Bridge about 1915	0.31	0.29	0.96	–	–	–	–	–	–
Silten (U.S. Steel Corp., etc.) (common silicon structural)	0.40	0.25	0.80	–	0.20	–	–	–	–
U.S. Navy 1910	0.30	0.70	0.75	–	0.35	–	–	–	–
Freund 1925 (Former German)	0.13	1.05	0.57	–	0.18	0.08	–	–	–
Mauretania 1907 (English)	0.21	1.12	0.70	–	–	–	–	–	–
Chromador*** (Dorman Long & Company, England)	0.22	–	0.80	–	0.30	0.90	–	–	–
Cromansil (Electro Metallurgical Company)	0.15	0.75	1.25	–	0.30	0.50	–	–	–
Union Baustahl (German)	0.15	0.25	0.80	–	0.55	0.40	–	–	–
Man. High Ten. (Granite City)	0.14	0.17	0.80	–	0.30	0.12	–	–	–
Centralloy (Central Steel)	0.15	–	0.75	–	0.50	0.25	–	–	–
Konik**** (Continental St.)	0.09	–	0.35	–	0.20	0.10	0.40	–	–
Corten (U.S. Steel Corp.)	0.10	0.75	0.20	0.15	0.40	1.00	–	–	–
70-90 (Alan Wood)	0.25	–	0.45	0.10	0.45	–	–	–	–
Hi-Steel (Inland)	0.10	0.15	0.45	0.12	1.00	–	0.50	–	–
HT 50 (Armco)*****	0.10	–	0.50	0.10	0.60	–	0.40	0.10	–
Double Strength (Republic)	0.08	–	0.70	–	1.40	–	0.75	0.10	–



* Compositions approximate-not necessarily that preferred by the maker, but within his limits
** May appear
*** Tiscoten (Tata Iron & Steel Co., India) is similar
**** Lower yield strength, designed for cold-drawing
***** Composition guessed at from maker's statement as to ranges



"Konik" Steel is Used in Producing Tire Chains and Ball Bearings as well as for Padlock Clasps, Conveyor Chains, etc. (Courtesy of Continental Steel Corp.)

One Stage in the Construction of Cars for the High Speed Line over the Delaware River Bridge at Philadelphia. "A.W. 70-90" steel was used in practically all the stress members. The cars were built by the J. G. Brill Co. (Courtesy of Alan Wood Steel Co.)

by the alloy producing companies which include "Cromansil," developed by the Electro Metallurgical Co.; manganese-vanadium, sponsored by the Vanadium Corp. of America; and the carbon-molybdenum and manganese-molybdenum steels of the Climax Molybdenum Corp. One of the tables, reproduced herewith, lists the chemical composition of all of these steels, the earlier and the more recent ones.

Some of these steels are quite fresh eggs, the last one having been laid in January. As a new one has been laid every two months for quite some time past, it's about time for still another, so another cackle should be due as this appears. Nobody expects that every one of these eggs is going to hatch, but it is difficult to know how to candle such eggs. About all that can be done at the moment is to sort them into white and brown.

In the metallurgical discussion of these steels in the two symposia referred to, the chairmen of the committees arranging for the sessions decided to play no favorites and, instead of having each steel mill hen, just off the nest, tell about her own egg, to get the whole clutch described by others. This task happened to fall upon the editorial staff of the METALS & ALLOYS as represented by the papers by Gillett and Cone. Besides these, at the A.I.M.E. Symposium Epstein, Nead and Halley not only described the egg, but analyzed the process of laying it.

These papers should be consulted for detailed statements of makers' claims for mechanical and other properties and for references to prior literature.

We may briefly summarize here some of the points brought out in those papers.

High Yield-Strength Alone Easily Obtained

There is no difficulty at all in getting 50,000 lbs. per sq. in. yield strength cheaply, if that were all that were required, for it can be gotten in a high carbon steel. The trouble is that such a steel lacks the toughness and formability as well as the weldability needed in modern structural work. It would be no chore to take a medium carbon low alloy steel and heat treat it to give this yield together with great toughness, but the strength wouldn't be there after welding and

Table of Carbon and Low Alloy Steels—Range of Percentage Composition Reported by Companies.—(From the paper by E. F. Cone)

Type	C	Mn	Si	Cu	Ni	Mo	P **	Other
CARBON STEELS								
SAE 1030	0.25–0.35	0.50–0.80	.....	.....	.....	.....	.....	.....
SAE 1015	0.10–0.20	0.30–0.60	.....	.....	.....	.....	.....	.....
EARLY STEELS								
SAE 2115	0.10	0.30	0.15	.....	1.25	.....	.....	.....
2-2½ Ni	0.20	0.60	0.30	.....	1.75	.....	.....	.....
	0.20	0.40	.....	.....	2.00 †	.....	.....	.....
	0.20	0.80	.....	.....	2.00 †	.....	.....	.....
SAE 2300	0.45 *	.....	.....	.....	3.50	.....	.....	.....
SAE 3130	0.25–0.35	0.50–0.80	.....	.....	1.0–1.5	.....	.....	0.45–0.75 Cr
SAE 3115	0.10–0.20	0.30–0.60	.....	.....	1.0–1.5	.....	.....	0.45–0.75 Cr
SAE 4630	.....	.....	.....	.....	.....	.....	.....	.....
SAE 4615	0.10–0.20	0.30–0.60	.....	.....	1.5–2.0	0.20–0.30	.....	.....
Med.-Mn.	0.20–0.25	1.00–1.75	.....	.....	.....	.....	.....	.....
Sil. Struct.	0.30–0.40	0.70–0.90	0.20–0.30	.....	.....	.....	.....	.....
Cr-V	0.15–0.25	0.50–0.80	.....	.....	.....	.....	.....	0.80–1.10 Cr, 0.15 V†
Cromansil	.....	1.00–1.40	0.60–0.90	..... ‡	.....	.....	.....	0.40–0.60 Cr
Mn-V	0.13–0.18	1.20–1.45	0.15–0.25	.....	.....	.....	.....	0.09–0.12 V
C-Mo	0.08–0.15	0.70–0.90	0.20–0.30	0.20 ‡	.....	0.20–0.30	.....	.....
Mn-Mo	0.10–0.20	1.20–1.40	0.20–0.30	0.20 ‡	.....	0.20–0.30	.....	.....
STEEL CO. STEELS								
Cor-Ten	0.10	0.10–0.30	0.50–1.00	0.30–0.50	.....	.....	0.10–0.20	0.50–1.5 Cr
Man-Ten	0.35 *	1.25–1.70	0.10–0.30	0.01–0.25	.....	0.00–0.40	.....	0.00–0.20 V
Sil-Ten	0.20–0.40	0.40–0.80	0.20 †	0.01–0.25	.....	.....	.....	.....
Yoloy	0.08–0.22	.....	.....	1.0	2.0	.....	.....	.....
RDS-1	0.12 *	1.00 *	.....	0.5–1.5	0.5–1.0	0.20 *	.....	.....
RDS-1A	0.30 *	1.00 *	.....	0.5–1.5	0.5–1.0	0.20 *	.....	.....
Hi-Steel	0.12 *	0.50–0.70	0.30 *	0.9–1.25	0.45–0.65	.....	0.10–0.15	.....
HT-50	0.12 *	0.15–0.90	Trace	0.30–0.80	0.30–0.80	0.05–0.25	0.05–0.15	.....
AW 70-90 A / AW 70-90 B	0.25 *	0.75 *	0.25 *	0.30–0.50	0.25 *	.....	0.08–0.10	0.25 Cr *
Jal-Ten	0.35 *	1.25–1.75	0.30 *	0.40 †	.....	.....	.....	.....
Gr. City 1	0.14	0.70–0.90	0.15–0.20	0.25–0.30	.....	.....	.....	0.12 Cr
Gr. City 2	0.20–0.30	1.20–1.60	0.15–0.20	0.25–0.30	.....	.....	.....	0.12 Cr
Centralloy	0.08–0.30	0.60–0.90	0.50 *	0.40–0.60	0.25 *	Yes	.....	0.25 Cr *
Konik	.....	.....	.....	0.10–0.30	0.20–0.50	.....	.....	0.07–0.30 Cr

* Max. † Min. ‡ Optional. ** P and S range is 0.35 to 0.55 max. unless otherwise given.

A Large Oil Tank Truck Constructed Largely of Republic "R.D.S." Grade 1 Steel for the Sun Oil Co. The capacity of this truck was increased by 300 gals. due to the saving in weight. (Courtesy of Republic Steel Corp.)

for practical reasons heat treatment is out of it anyhow; the steel must show the desired properties as rolled, or at least with only a normalizing treatment.

Even with these limitations there is no difficulty in getting what is wanted—a low carbon, 3 per cent, or

Free Bend Test of ¾-In. Thick Manganese-Vanadium Plate Welded with Coated Rod of Similar Composition. The piece has been stress-relieved at 1200 deg. F. and the tension properties are: Yield point, 66,900 p.s.i.; Tensile strength, 87,050 p.s.i.; elongation in 2 in., 20.5 per cent; reduction of area, 51 per cent. The break occurred in parent metal. (Courtesy of Vanadium Corp. of America.)

a medium carbon, 2.5 per cent, nickel steel meets every mechanical requirement, but it is a bit costly. Moreover, as the engineer decided to cut down his sections to utilize the higher yield strength, he began to be concerned about corrosion resistance, so he added another requirement—that the steel must have enough better corrosion resistance than ordinary copper-bearing structural steel so that the thinner section will not scale off nor pit through any faster than the thicker section of ordinary steel.

Other Properties Involved

The problem then became set as the development of a 50,000 lbs. per sq. in. yield strength steel with the formability and weldability of 2.5 per cent nickel steel, but with demonstrably better corrosion resistance and at a lower cost. There was no one answer in the back of the book.

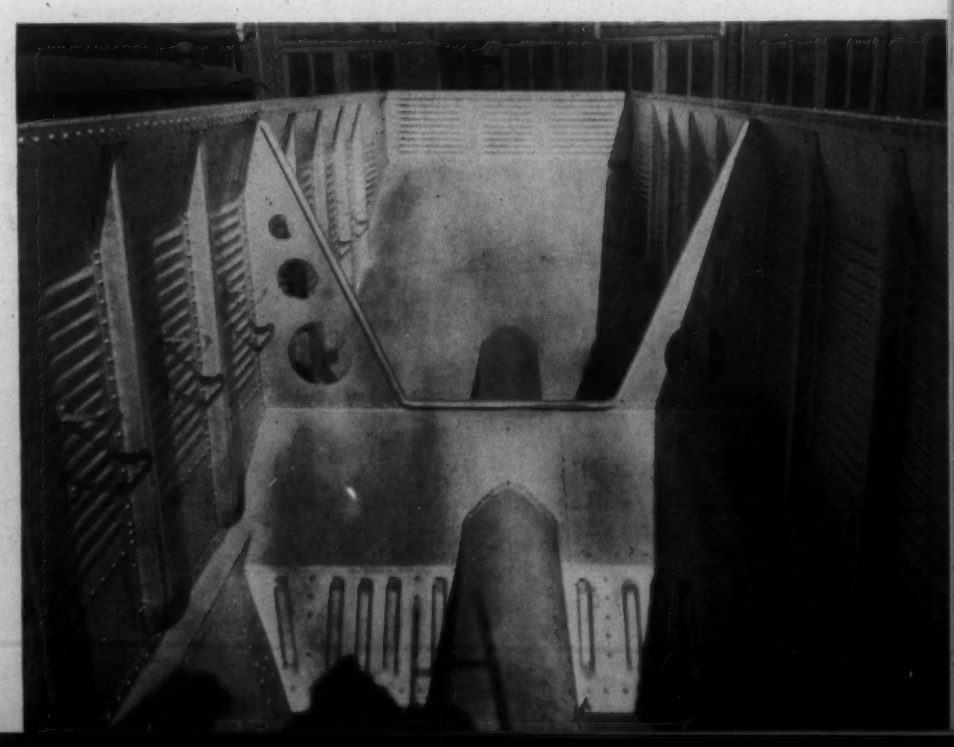
The various steps in working toward the answer, in metallurgical rather than chronological order, are shown in one of the accompanying tables, based on the paper by Gillett. In many cases the makers allow themselves quite a range of composition, varying it according to the sections to be rolled, etc. In such cases the compositions given in this table are taken within the makers' ranges, but are not necessarily just the composition they would themselves choose. Another table gives the producers' compositions. Space is lacking to discuss all the changes that can be rung.

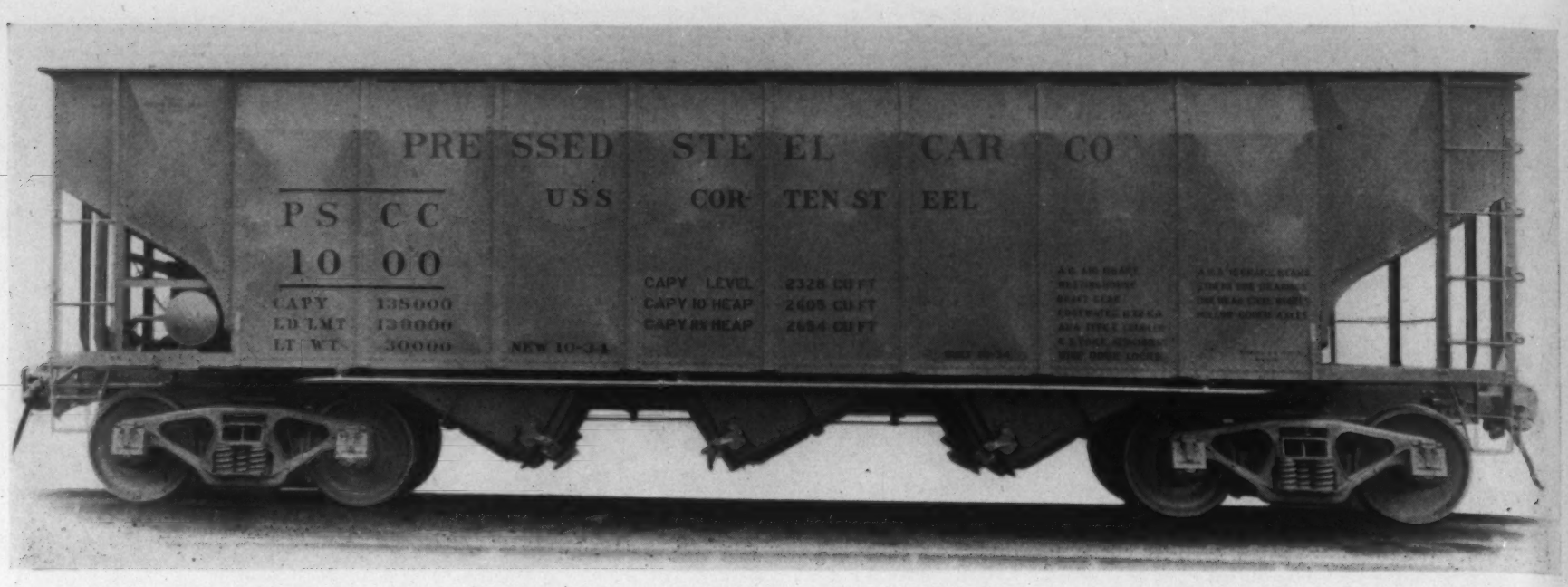
"Yoloy" gets the properties of nickel steel by using nickel, regardless of cost, and, by using high copper, secures corrosion resistance as well as the behavior of a higher Ni content, since, within limits, the sum of Ni plus Cu acts pretty much as though it were all nickel.

Atmospheric Corrosion

One outstanding metallurgical fact in this series of steels is the unanimous acceptance of the resistance to atmospheric corrosion of copper-bearing steel. Only the very old members of the group omitted it. It is optional in a few modern ones, but there is an overwhelming tendency to use copper, and to raise it above the usual "copper-bearing steel" range, both for enhanced corrosion resistance and for its strengthen-

The Inside of a Corrugated Hopper Car, Built of Republic "R.D.S." Steel for the B. & O. R. R. which Illustrates Quite Clearly the Design of Construction Employed to Secure the Same Strength with Less Weight through the Use of Lighter Gage Alloy Steel. (Courtesy of Republic Steel Corp.)





A Coal Car Constructed of "Cor-Ten" Steel, Produced by the American Sheet & Tin Plate Co., by the Pressed Steel Car Co. (Courtesy of United States Steel Corp.)

ing effect. Incidentally, those steels utilizing over 0.60 per cent Cu have an added possibility for strengthening by precipitation hardening, if desired. The steels with 0.60 per cent Cu or over contain as a minimum around half as much nickel as copper because of the tendency of high-copper steels to surface-check in rolling, a fault overcome by the use of a small proportion of nickel.

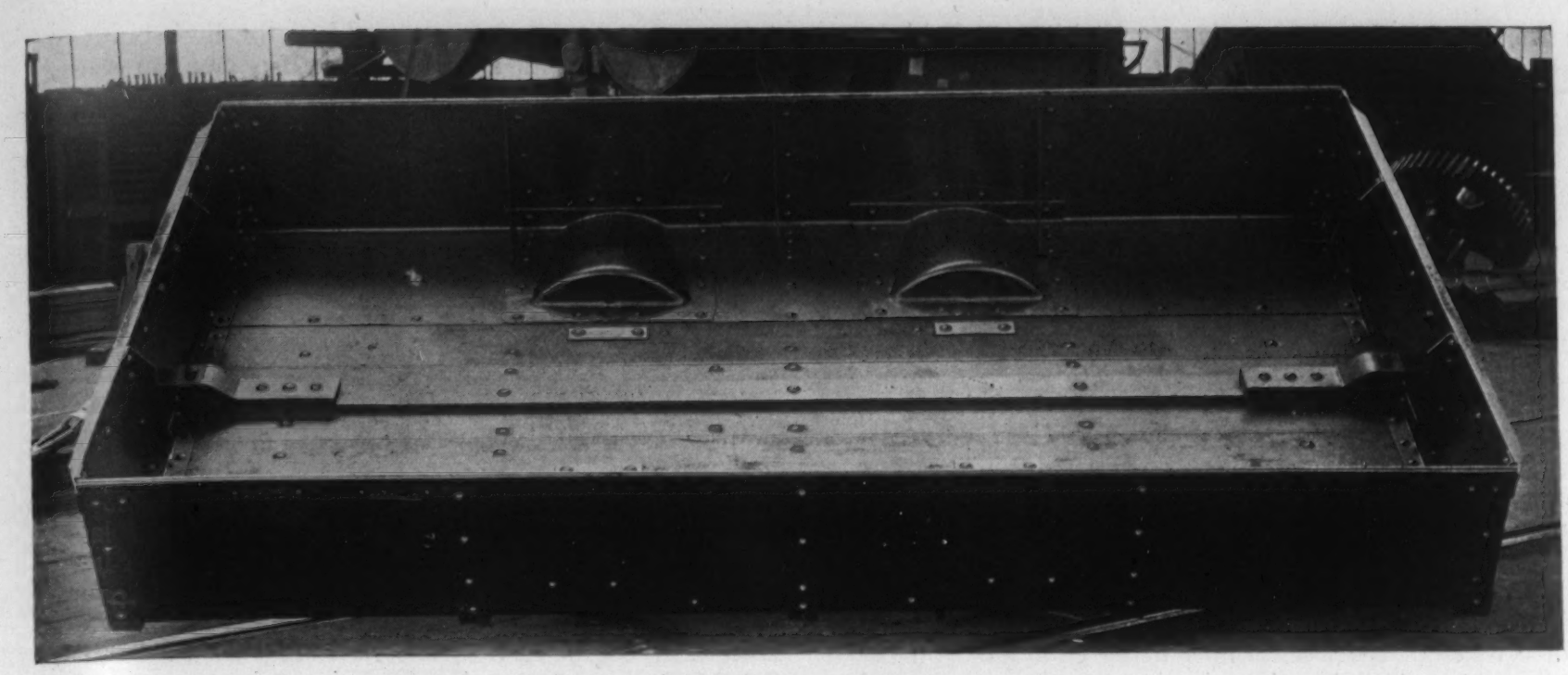
As the Gillett table shows, the early attempts were along the lines of raising the manganese or silicon contents of the steel, or both. Concurrently, the carbon was dropped, for the danger of brittleness when carbon and manganese are both high became evident. High silicon was tried, but failed to give uniformity of properties in sections of varying thickness. Primarily to remedy this, chromium was resorted to. No claims for corrosion resistance of chromium steels with not over 1 per cent Cr were made for the early steels of this type. Claims are now being made for enhanced corrosion resistance when a little chromium or nickel, or both, are added to a copper-bearing steel, but not much very convincing evidence has yet been adduced. Maurer and Heine [2] cite 3-year exposure tests at Freiberg in which some superiority is indicated for chromium steels with 0.35 and 0.65 per cent Cr in conjunction with fairly high copper, but if the roll scale was removed only a slight improvement was noted.

Phosphorus as an Alloy

A very interesting metallurgical step was taken when phosphorus was taken from the class of "nuisance elements" and dignified as a true alloying element. This was done primarily because, as the A.S.T.M. exposure tests showed and Storey first pointed out, phosphorus markedly improves the corrosion resistance of copper steels. Phosphorus also has a very potent effect in raising yield strength. The combination of high phosphorus and high carbon, if overdone, may lead to brittleness. On account of the possibility of segregation of phosphorus, it is necessary to stay on the safe side, especially when other hardening elements are present in considerable amount, and still more especially when those are used that lead to air-hardening after welding.

Hence, there is a tendency to set the sum of C plus P at not over 0.25 per cent. There is a possibility of corrective action of other elements upon the embrittling tendency of phosphorus, which may ultimately allow safely utilizing more generous amounts, but in so doing the corrective elements should be held within permissible air-hardening limits. Shock re-

A Special Type of Trolley Bus, Built by Pullman-Standard, Worcester, Mass., for the United Electric Railways, Providence, R. I. "Cor-Ten" steel was used in its construction. (Courtesy of United States Steel Corp.)



The Body of this Mine Car is Made of "Cor-Ten" Steel with the Frame of "Man-Ten" Steel, Furnished by the American Sheet & Tin Plate Co. (Courtesy of United States Steel Corp.)

sistance of welds seems quite important and shock resistance should be maintained down to low temperatures.

Carbon of 0.15 Per Cent Suggested as Maximum

The gradual slicing-down of carbon has gone on until one can almost take 0.15 per cent C as the upper limit in the more modern types. Epstein, Nead, and Halley explain this, together with the tendency toward phosphorus, copper and nickel, and the avoidance of high manganese, on the basis that carbon raises the tensile much more rapidly than the yield; manganese does so almost as much as carbon; silicon, molybdenum, and chromium raise the tensile somewhat more than the yield; nickel has equal effect on both; while copper and phosphorus each raise the yield much more than the tensile. There seems to be reason for, as well as a tendency toward, holding the tensile down when the yield is forced up, in order to give maximum formability, toughness, and freedom from too rapid hardening by cold working upon permanent deformation.

Molybdenum and vanadium seem to exert a beneficial effect on the alloys from several points of view, but, on account of cost, they appear in relatively few of the steels.

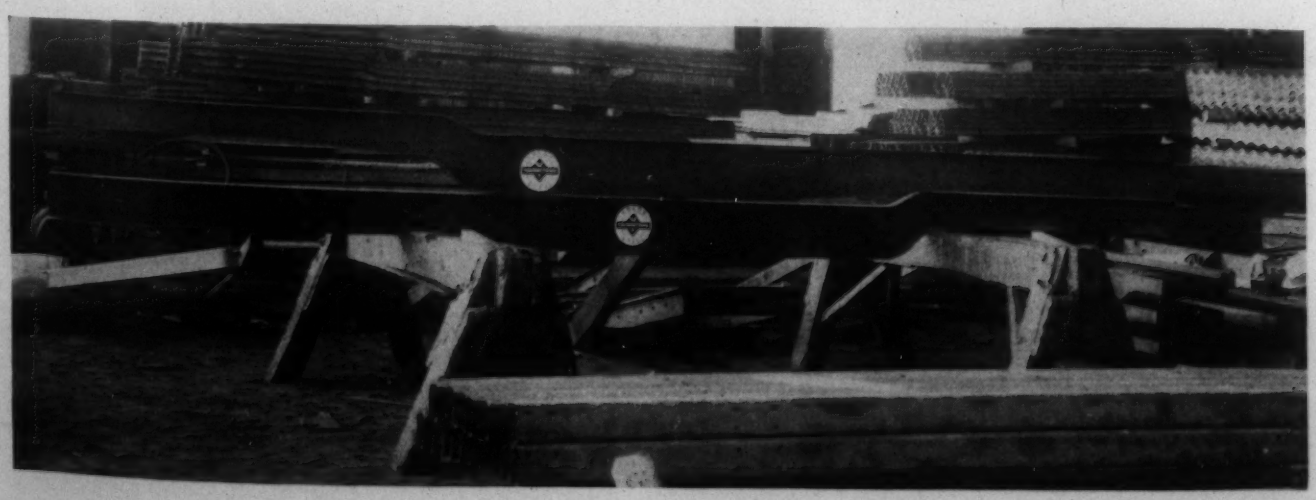
As the tables show, a wide variety of permutations and combinations may be used to produce high yield-strength steels. Various compositions not used commercially are mentioned in some of the papers, and there are other combinations and other alloying elements that might be employed and still meet the usual mechanical tests.

The hatching or addling of the eggs will depend on fine-haired distinctions that are not readily evaluated in quantitative fashion. Weldability, dependability of

Large Pressure Vessel for Low Temperature (—50 deg. F.) Oil Refining Service Made of 2 Per Cent Nickel Steel. (Courtesy of International Nickel Co.)

avoidance of brittleness after welding in all ranges of composition and all sections, formability, low temperature toughness, and actual corrosion resistance, known by long-time service results instead of guessed at by laboratory or limited exposure tests, will ultimately have to be demonstrated.

Some of the low-carbon steels have remarkably high endurance limits. This has so far been demonstrated for "Hi-steel," "H.T.50," and "Corten," all



Trailer Side Frame Members Cold Formed from "Yoloy" Steel. (Courtesy of Youngstown Sheet & Tube Co.)

steels of the phosphorus class, and this may hold for some of the other low-carbon steels.

The metallurgist has proved that he can produce not one, but many answers to the problem set. As the true requirements of the engineer become more apparent and as more adequate testing methods become available for determination of important properties not now satisfactorily measured, he can doubtless modify, adjust, and perfect the present steels, or others like them, to produce just what is wanted, and do so at a cost that will enable the designer to use them.

Some of these steels, probably several of them, are here to stay. They form a superior class of structural steels that seems destined to replace plain carbon structural steel for an important proportion of the tonnage.

The symposium of the mining engineers was opened by an address by J. J. Pelley, president of the Association of American Railroads, Washington. He outlined some of the experiments now being conducted on the railroads with lightweight equipment, passenger and freight, made possible by new types of metal alloys. In addition to the well-known lightweight passenger trains, of which there are now some 40 units in service, he described the construction by the Association of American Railroads of experimental lightweight freight cars. In one type of car, built with ordinary carbon steel, superior design has made possible a weight reduction of two tons under the former standard car. Other cars, built with alloy metals and weighing 6 or 7 tons less than former cars, are now under test.

"If these tests are successful," said Mr. Pelley, "a very large field for the use of lighter weight metals will immediately be opened, provided the costs of such metals are not too high. Railroads own today about 550,000 fewer cars than they did at the high point of ownership and, in addition, are expected to retire 100,000 more this year. Since 1923 there have been put into service 931,000 new cars and 15,500 new locomotives. There have been retired, since 1923, 1,230,000 cars and 32,940 locomotives, by reason of obsolescence. Increased efficiency in the better movement of equipment, more prompt handling on the part of shippers, reduction in time out of service for repairs because of the acquisition of so large a number of new cars, have combined to add so much to the serviceability of equipment that it is reasonable to assume that the railroads will be able to furnish adequate service to the public with at least 300,000 fewer cars than were used at the high point of ownership.

"An upturn in business of as much as 20 or 25 per cent will require, however, the addition of a large number of cars. The great importance and the large field for increased use of improved materials in equipment construction are readily apparent. However, it must be recognized that the railroads, owning nearly 2,000,000 cars, cannot change their equipment or styles from year to year. Their position is different from that of concerns which manufacture things to sell to the public. The railroads buy things to use in producing a service of transportation, and must carefully weigh the advantages of the new against the old before making departures that would result in large expense of doubtful economic value. To change equipment wholesale to meet supposed new conditions would not only be impossible but uneconomical."

References

[1] A. E. Gibson. "The Development and Use of Low Alloy, High Tensile Steels." *Journal*, American Welding Society, Vol. 14, Sept. 1935, pages 2-8.

[2] E. Maurer and H. Heine. "Festigkeitseigenschaften und Korrosionsverhalten von Hochbaustählen." *Archiv für das Eisenhüttenwesen*, Vol. 9, Jan. 1936, pages 345-357.

Table of Typical Physical Properties of Low Alloy Steels as Reported by the Producers to E. F. Cone.

Type	Yield Point, p.s.i.	Tensile Strength, p.s.i.	Elong. in 2 in.	Red. of Area, Per cent	Izod Ft. Lbs.	Remarks
EARLY STEELS						
S.A.E. 2115	45,400	67,400	35.5	68.8	..	1 in. dia., hot rolled
2-2½% Ni	48,500	75,900	28.8	59.4	..	¾-in. plate
	54,800	77,600	28.2	55.3	..	¾-in. plate
	46,600	77,000	28.0	61.0	65	1-in. plate
S.A.E. 2300	62,300	101,900	33.5	47.4	56	½-in. plate, as rolled
	58,000	85,000	27.0	58.0	..	1½-in. round, as rolled
S.A.E. 3130	68,000	96,000	27.0	60.0	..	Small section, normalized
S.A.E. 3115	56,000	76,000	33.0	72.0	..	Small section, normalized
S.A.E. 4630	72,000	103,000	34.0	49.0	..	Small section, normalized
S.A.E. 4615	56,000	84,000	31.0	63.0	..	Small section, normalized
Med Mn	50–90,000	85–120,000	....	....	..	As rolled
Sil. Struct.	45,000+	80–95,000	....	....	..	As rolled
Cr-V	55–80,000	85–124,000	15–20*	40–55	..	⅜ to 1½-in. plate, annealed
Cromansil	48–91,000	75–143,000	16–30*	43–63	20–36	⅜ to 2-in. plate
Mn-V	58–71,500	82–94,000	23–18.5*	64–50	60–110	⅜ to 1-in. plate, hot rolled
C-Mo / Mn-Mo	45–55,000	60–90,000	....	....	..	
STEEL CO. STEELS						
Cor-Ten	50–60,000	65–75,000	27–22	....	60	End. Limit—45,000 p.s.i.
Man-Ten	55,000	90,000	20.0	....	40	End. Limit—40,000 p.s.i.
Sil-Ten	45,000	90,000	18.0	....	..	
Yoloy (0.08 C)	58,300	71,400	24.0*	....	..	¼-in. plate, hot rolled
	61,000	75,000	32.0	60.0	43**	¾-in. rd. (.505 in), hot rolled
	63,300	75,800	24.0	....	..	⅛-in. strip, hot rolled
(0.15 C)	65,000	82,700	23.0*	....	..	¼-in. plate, hot rolled
	64,000	82,000	28.5	60.0	41**	¾-in. rd. (.505 in), hot rolled
	64,600	84,400	26.0	....	..	8 ga. strip, hot rolled
(0.22 C)	68,600	94,800	22.5*	....	..	½-in. plate, hot rolled
	61,000	88,000	27.0	57.0	..	¾-in. rd. (.505 in), hot rolled
	71,400	97,900	20.0	....	..	⅛-in. strip, hot rolled
R.D.S.-1	60,000	75,000	25.0	....	75	
R.D.S-1A	70,000	90,000	18.0	50.0	..	
Hi-Steel	69,100	77,900	22.0*	68.0	41.7–35.8**	0.125 gage, as rolled
	71,360	81,800	20.5	....	..	18 gage, hot rolled & annealed
H.T.-50	47,000	67,000	28.0	....	..	Hot rolled
	52,000	70,000	25.0	....	..	Cold rolled
A.W. 70-90A	70,000	90,000	20.0	....	50	
A.W. 70-90B	50,000	65,000	25.0	....	50	
Jal-Ten	50,000	80,000	20.0	....	40	End. Limit, 50% of T.S.
Gr. City 1	70,000	80,000	19.0	....	..	As rolled
Gr. City 2	85,000	105,000	12.0	....	..	As rolled
Centralloy (Med.)	50–60,000	65–75,000	25.0	....	..	As rolled, annealed or normalized
Centralloy (High)	60–72,000	75–90,000	20.0	....	..	As rolled, annealed or normalized
Konik	35–120,000	48–122,000	....	....	..	Soft wire of various sizes

* In 8 in. ** Charpy.